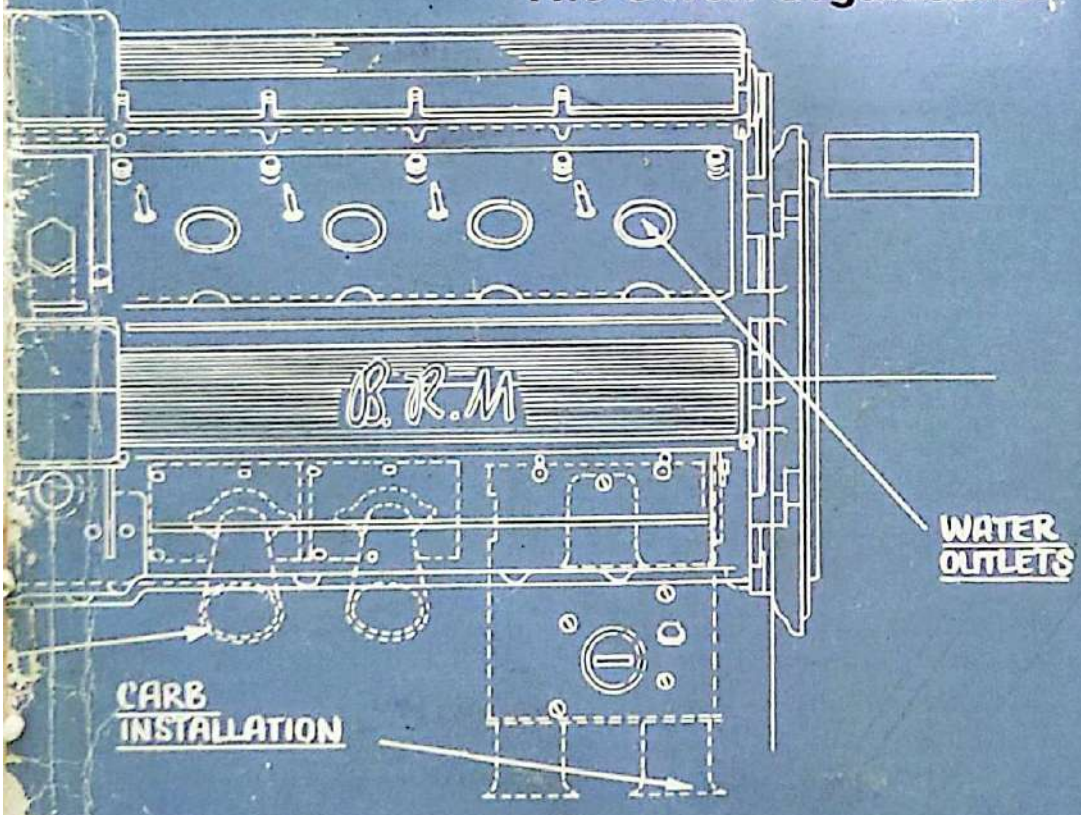
Some aspects of

MOTOR RACING RESEARCH

The Owen Organisation



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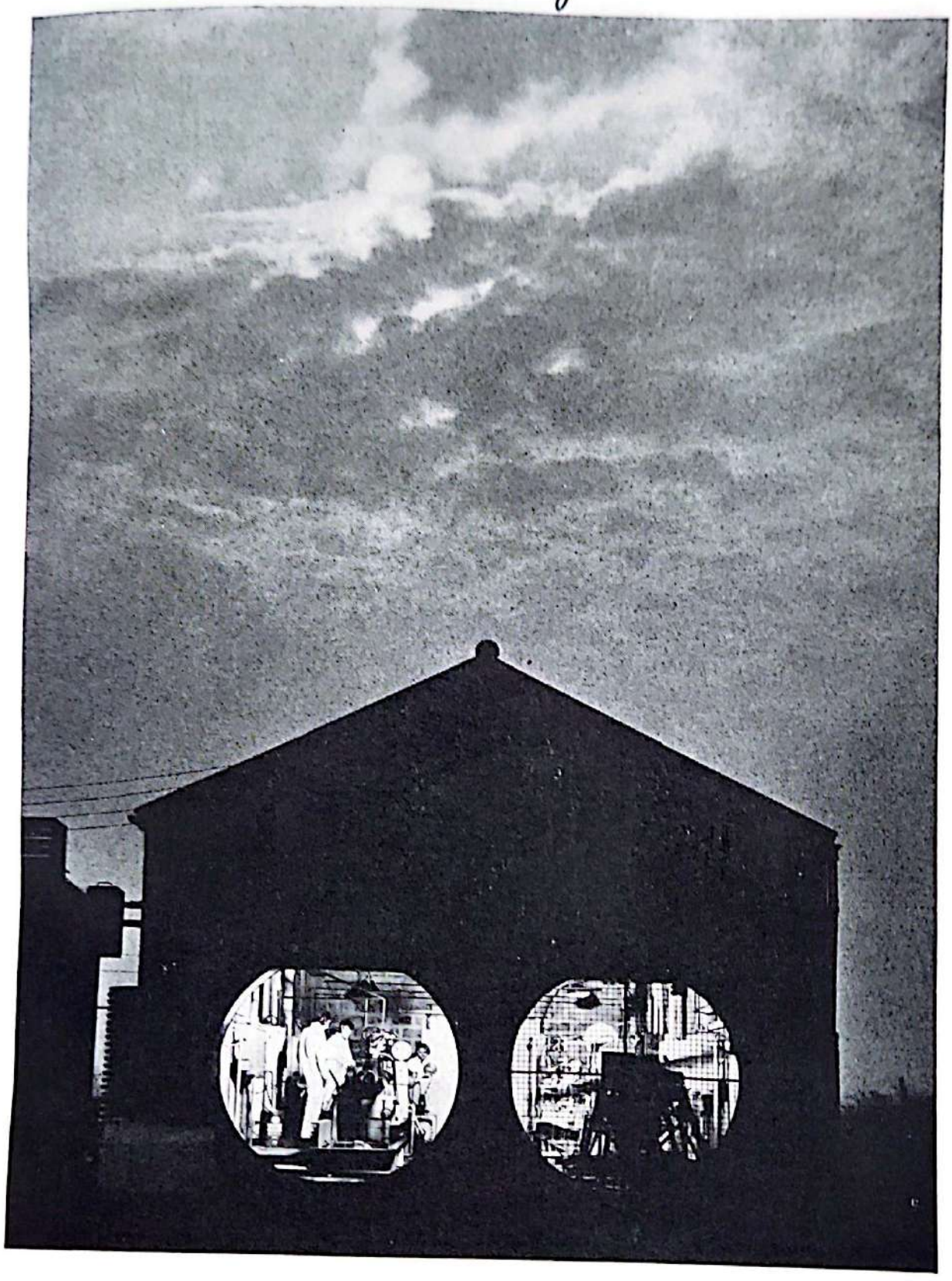
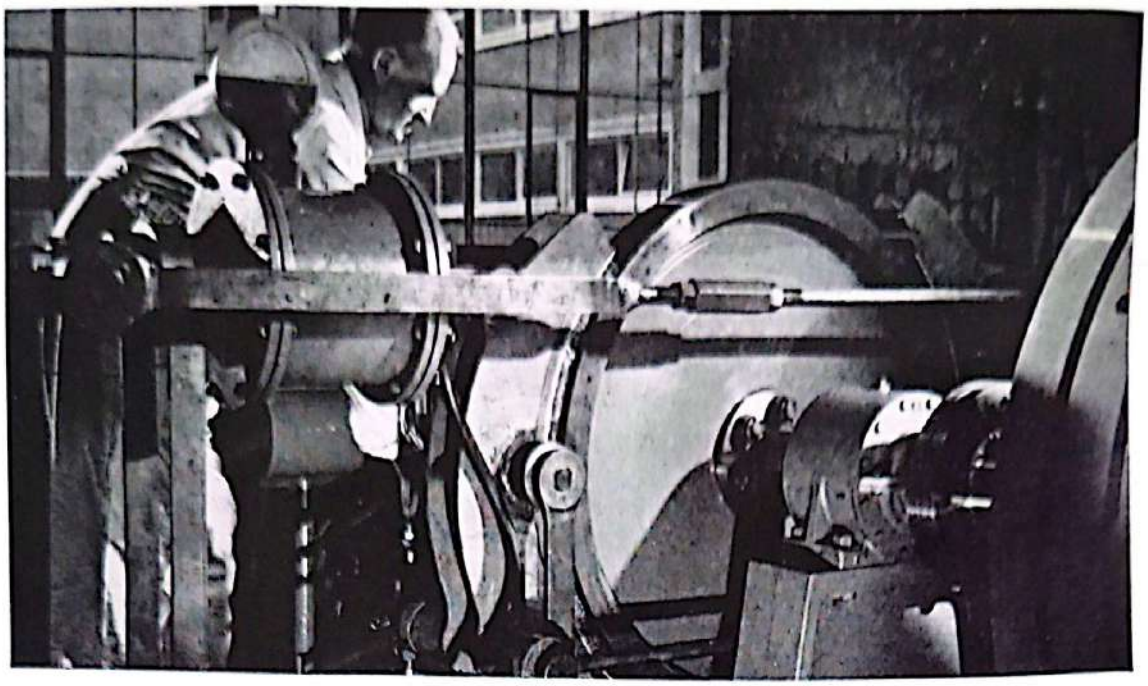


You're looking at one of the noisiest nights of the year

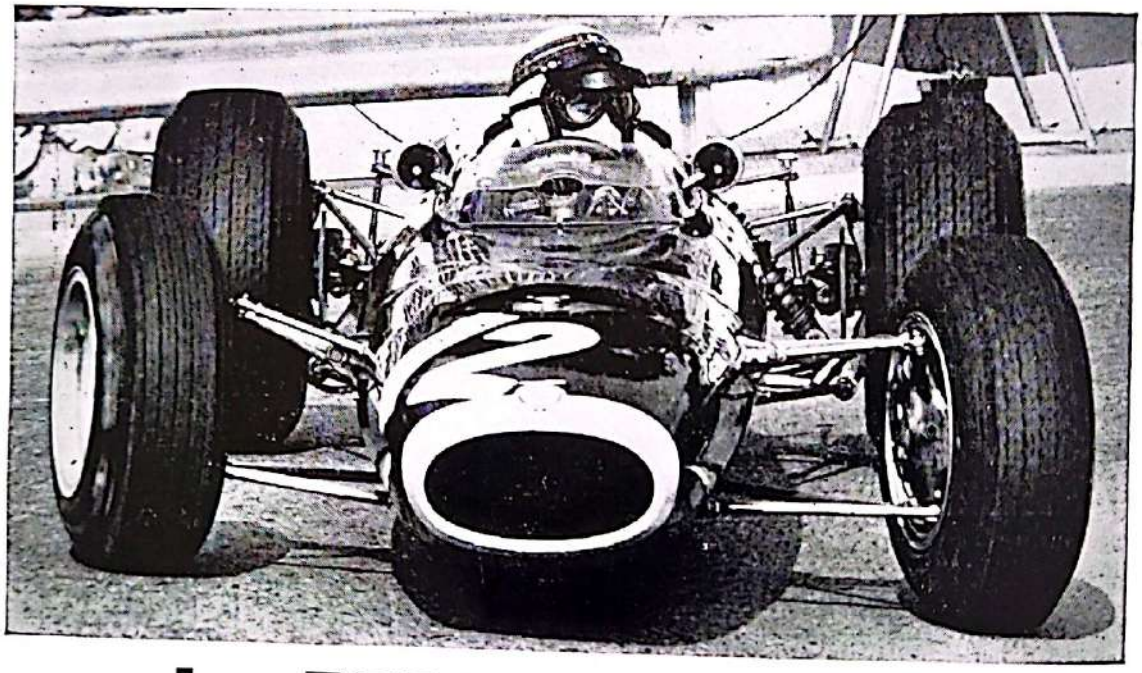
DON'T BE FOOLED by that gentle sky, this scene is full of sound and fury. In that shed BRM are testing a racing engine. They'll test it all night, often at full revs, and the only thing they can do about the noise is to go some place where it doesn't matter. (Like the disused Folkingham airport, where this picture was taken.) Shell are part of this scene. They have been associated with BRM since the very early days, both in development and on the track. It's a very active partnership – in the circumstances, a sleeping partnership would be out of the question.

SHELL



testing RPM

This is a dynamometer in the Ferodo Test House. It can simulate any condition, whether realistic (say, 200 laps of Brand's Hatch with so many brake applications per lap) or an "overload" test to ultimate destruction.



proving BRM

This is a BRM, with Jackie Stewart at the wheel, heading for yet another victory (in this case, The Monaco Grand Prix).

An important factor in the success of BRM cars is their ability to slow fast as well as go fast.

Ferodo Limited have always regarded motor racing as the final proving ground for their product and the results of collaboration between The Owen Organisation and Ferodo Limited is written in the record books . . .

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some aspects of

MOTOR RACING RESEARCH

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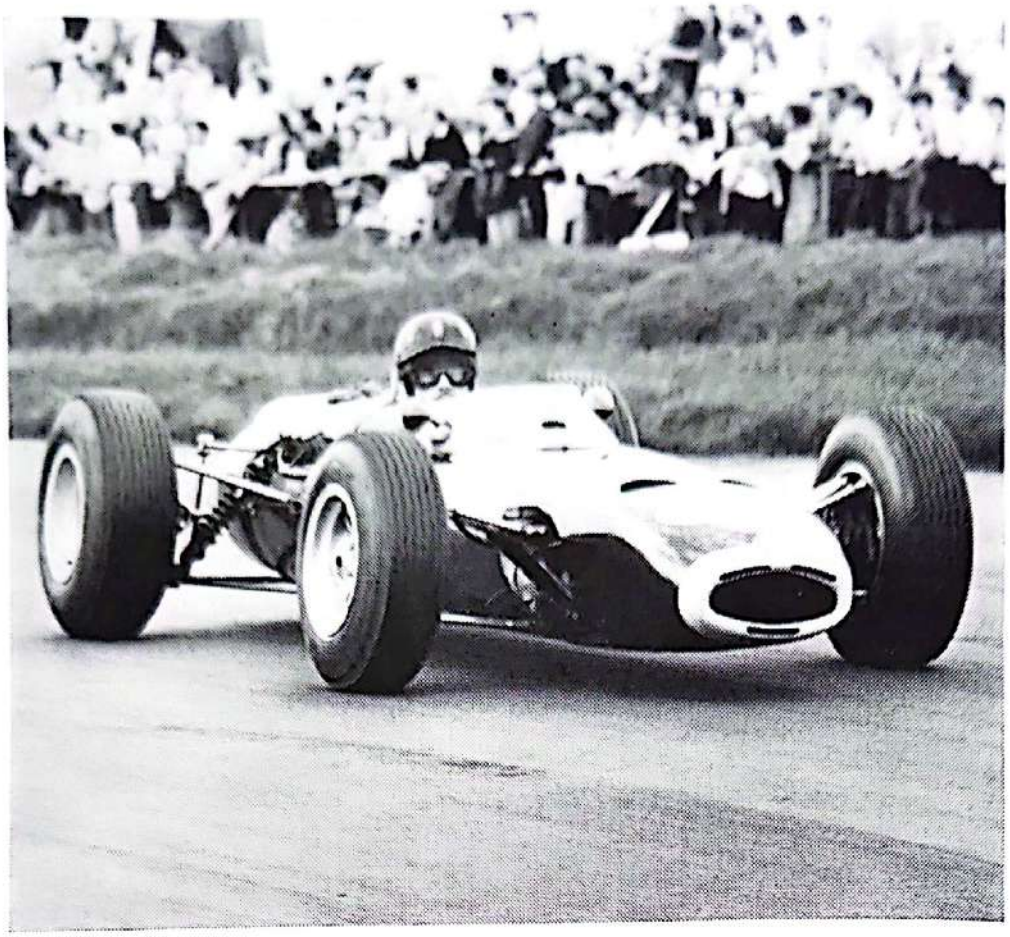

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1. INTRODUCTION

Externally Motor Racing appears specialised, exotic and glamorous. Eulogies have been written about the smell of the engines and recordings of noise have a wide sale. Cars have been described as phallic symbols. This combined with the basic human reaction to risk and the possibility of blood has produced a distorted "image".

The truth is that motor racing today is an international professional commercial activity and research and development in this field is a normal form of Industrial Research (A).*

The writers are associated with a large international engineering manufacturing organisation which has a department which designs, develops, produces and races Grand Prix, Formula I, single-seater automobiles. Because of this background the Owen Organisation has been associated with other competitive ventures such as the Bluebird land speed record car, the Rover-B.R.M. Gas Turbine Car, the Matra-B.R.M. Le Mans car, Formula II engines, and is today connected with other fields of competitive automobile sport either directly or in a consultative capacity. Hence in describing motor racing research the majority of the examples must inevitably be illustrated with Owen Organisation B.R.M. activity. It should be emphasised that the paper is concerned with the higher forms of automobile competition and the observations are not applicable to club racing, and other amateur events though it must be recognised that this is the breeding ground of potential drivers and many engineers have reorientated their technology as result of personal participation.

* *Letters refer to References.*

FIG. 1. SELECTION OF TROPHIES WON BY B.R.M. TEAM CARS.

FIG. 2. TROPHY BY F.I.A. TO THE MANUFACTURER WHO WINS THE CONSTRUCTERS CHAMPIONSHIP FOR FORMULE I.

2. THE JUSTIFICATION OF MOTOR RACING

Inadequate Reasons

Motor racing, with the international competition, is inevitably an expensive occupation. Why, then, should an industrial organisation whose prime function is to be profitable through its operational efficiency, spend large sums of money annually on this activity? Certainly not to win trophies which grace the Boardroom (fig. 1). It is significant that the most important trophy, that awarded by the F.I.A. to the manufacturer who wins the constructers championship for Formula I cars, shown in fig. 2, is little larger than a teacup.

Perhaps to gain money? Though some of the individuals in motor racing may find it financially advantageous, if the Owen Organisation cars were to win every race in the Calendar, the overall effect on the annual budget would be almost insignificant. This probably applies to the competition side of any constructor.

Adequate Reasons

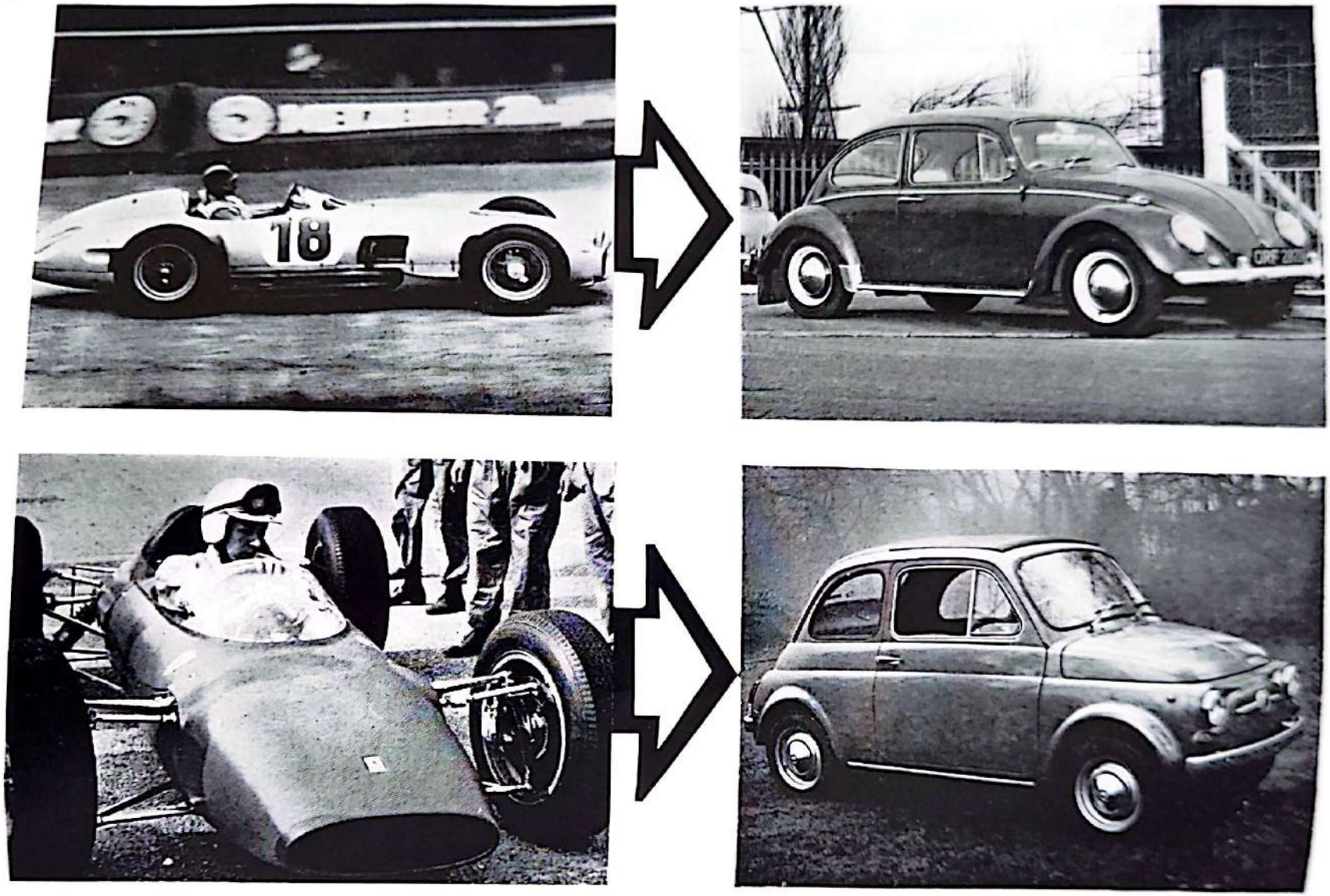
There are four reasons, at least, for the justification of motor racing by an industrial organisation:—

1. Motor Racing is an international sport in a techniquological environment and is **there,** in its own right, like that challenging mountain demanding to be climbed.
2. The acquisition of technical knowledge, trained specialists and facilities that can be utilised for associated commercial purposes.
3. The effect of success in international competition on the sale of automobile products produced by the successful country.
4. The influence of motor racing on component development.

The first reason is obvious and the second will be discussed later; the other two are worth separate consideration.

Influence on Export Markets

The success of Fangio driving Mercedes grand prix cars in the early 1950's did not only help to sell Mercedes cars; it also had a marked influence on the sale of commonplace Volkswagens (fig. 3). The success of Surtees in the Ferrari grand prix car, winning the Drivers and Constructors championships in 1964, does not only help to sell £10,000 sports cars; it also helps to sell ordinary 600 cc. Fiats. Success in international racing enhances the image of the engineering status of a nation. The coupling of Cooper with B.M.C. "Mini's", of Lotus with Ford and recently Ferrari with Fiat (with the Dino) is not just for technicalogical reasons in spite of their importance. The success of Honda and other Japanese Companies in international motor-cycle racing has had such a pronounced effect on their international commercial drive that today the British motor-cycle industry is sadly curtailed. It is significant that Honda have turned to the field of automobiles and in relatively short time achieved their first grand prix win at Mexico City on Nov. 7th, 1965, albeit with American tyres, British brakes, British inspired fuel injection equipment, etc. Almost coincidentally new sports cars designed and produced in Japan have made their appearance in the international market. Continued success by Honda could undoubtedly have an influence on say the sale of their S800 2-seater sports car which is in a similar field to several British cars. Historically it is pertinent that the first Grand Prix, worthy of the title, that held in France 1906 (see Appendix 1) had practical support from the French Government which recognised the importance of encouraging the automobile industry some 60 years ago.



FANGIO AND SURTEES SUCCESSES WITH MERCEDES AND FERRARI GRAND PRIX CARS HELP TO SELL EVERY DAY FAMILY CARS BY ENHANCING THE ENGINEERING STATUS OF THE MANUFACTURING COUNTRY.

On their part, the authors believe that the success of the Owen Organisation B.R.M. makes a positive contribution to the international prestige of the British automobile industry.

A comment by Raymond Mays (B) is relevant. He recounts how, having sent a letter to a number of firms who were thought to be interested in the original B.R.M. project:—"Waiting for the replies was an anxious time. The first two to reach me came from A. G. B. Owen, of the vast Owen Organisation, and the late Oliver Lucas, of Joseph Lucas Ltd. Both letters were encouraging and both invited me to visit the writers. I mention these two great businessmen because since then I have often thought how fortunate it was that their replies should be the **first** to come. The project might never have started if generous offers of assistance in cash and kind had not come when they did from these two industrialists".

Influence on Component Development

From a technologists viewpoint, the most important attribute of motor racing is its influence on the development of automobile components and the better understanding of vehicle and engine behaviour. Appendix 2 shows examples of the racing car constructors' willingness to accept the challenge of innovation.

It is outside the context of this paper to consider the technical history of racing cars which has been well documented elsewhere (C, D and E). A few examples will suffice:—

1. **1906.** Fig. 4 shows the legendary 12.986 litre Renault, weighing 990 Kg. which won the first Grand Prix worthy of the title, held in Sarthe, France, in that year. Driven by Francois Szisz with mechanic Marteau it averaged over 63 m.p.h. for a distance of 770 miles completed in 12 hours, 14 minutes, 7 seconds. Second was a 16.286 litre Fiat driven by Felice Nazzaro, weighing 1006 Kg., which completed the course in 12 hours, 46 minutes, 26.4 seconds. These cars were built to the formula given in Appendix A. The Renault was one of the early attempts at an aerodynamic shape and was fitted with a high tension magneto for which the formula was modified.

2. **1912.** Fig. 5 shows the 7.6 litre Peugeot car which won the 1912 French Grand Prix at an average speed of 68.45 m.p.h. for 956 miles on the Dieppe circuit, driven by Georges Boillot. The car, with an engine designed by Henri was the first in the modern technical tradition. The engine had four valves per cylinder, double overhead camshafts and hemispherical cylinder heads. There was a shaft (and not a chain) to the detachable Rudge-Whitworth wire wheels.

3. **1921.** Fig. 6 shows the 3 litre Duesenberg with a straight 8, four valves per cylinder engine, again designed by Henri. This was the first American car driven by an American driver, Jimmy Murphy ever to win a European Grand Prix. (Forty years later Phil Hill was the second American driver to win a European Grand Prix—we are still waiting for the second American car). The car is technically interesting in that it had a clean line that was followed for many years and was the first racing car with hydraulically operated brakes on all four wheels.

4. **1922.** Fig. 7 shows the 2 litre Daimler Benz known as the "Teardrop-wagon". The best position achieved by this car was a fourth but technically is was remarkable. It had a rear engine, independent rear suspensions by swing axles and inboard brakes. Further, the body shape was created on scientific areodynamic principles though such a shape is now known to be inferior to a sharp "cut off."

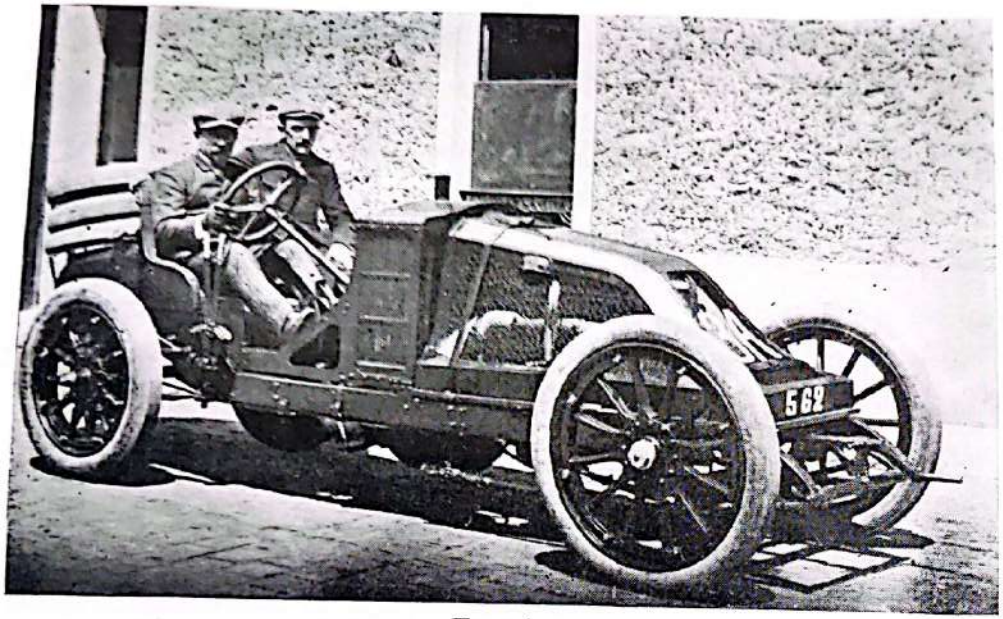


FIG. 4.
12.986 RENAULT WHICH WON THE FIRST GRAND PRIX, 1906 (G.P. CARS).

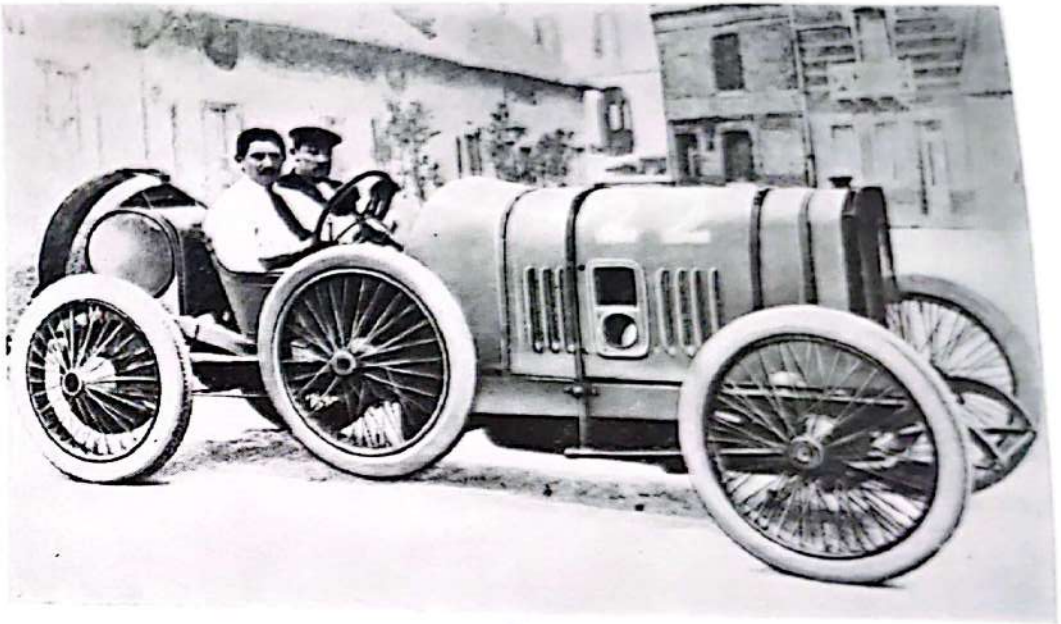


FIG. 5.
7.6 LITRE PEUGEOT, 1912.

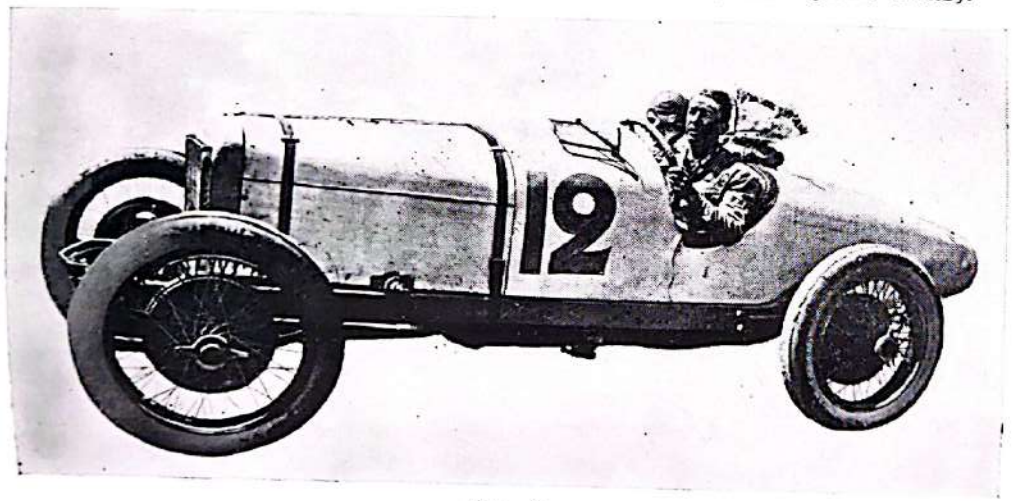


FIG. 6.
6.3 LITRE DUESENBERG, 1921.

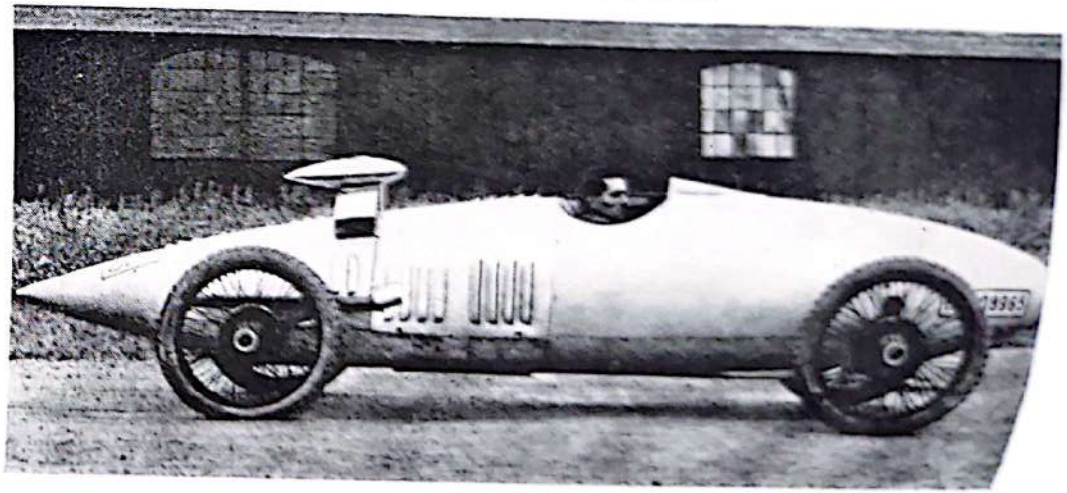


FIG. 7.
2 LITRE DAIMLER BENZ RACING CAR, 1922.

5. **1952.** Fig. 8 shows the 1½ litre supercharged B.R.M. developed from cars built for the 1947/53 formula. The evolution of the engine and its supercharging equipment has been described in the literature (E and F). The engine produced ultimately over 600 b.h.p. supercharged at over 60 lbs. per square inch. This was the first Grand Prix car to be fitted with disc brakes.

6. **1965.** Fig. 9 shows the 1965 Rover-B.R.M. gas turbine powered car. This was the first gas turbine powered car to compete in a race and be placed. The car was in the 2 litre class at Le Mans, was the first British car home being placed 10th overall. It was the first gas turbine fitted with heat exchangers ever to appear on a race track. Initial power was 145 b.h.p. but this had to be reduced substantially to below 100 b.h.p. due to engine component failures. Other than the engine, the car was faultless.

Thus the urge of competition forces the pace of development of wheels, tyres, electrical equipment and the principles of design to the benefit of automobile technology and the public.

3. COMPARISON OF MOTOR RACING RESEARCH WITH PRODUCTION AUTOMOBILE RESEARCH

General

Though the principles of Motor Racing Research follow the normal pattern of Industrial Research, there are differences in the emphasis on the prime factors when compared with research in the automobile industry.

Specification

Racing cars are built to international regulations (G and H) which give very close definitions of the requirements. There are no salesmen, no public opinion polls, no market research and no extraneous influences. A racing car is a projectile to carry a known driver around a known circuit as quickly as possible. Even colours are specified.

Time Scale

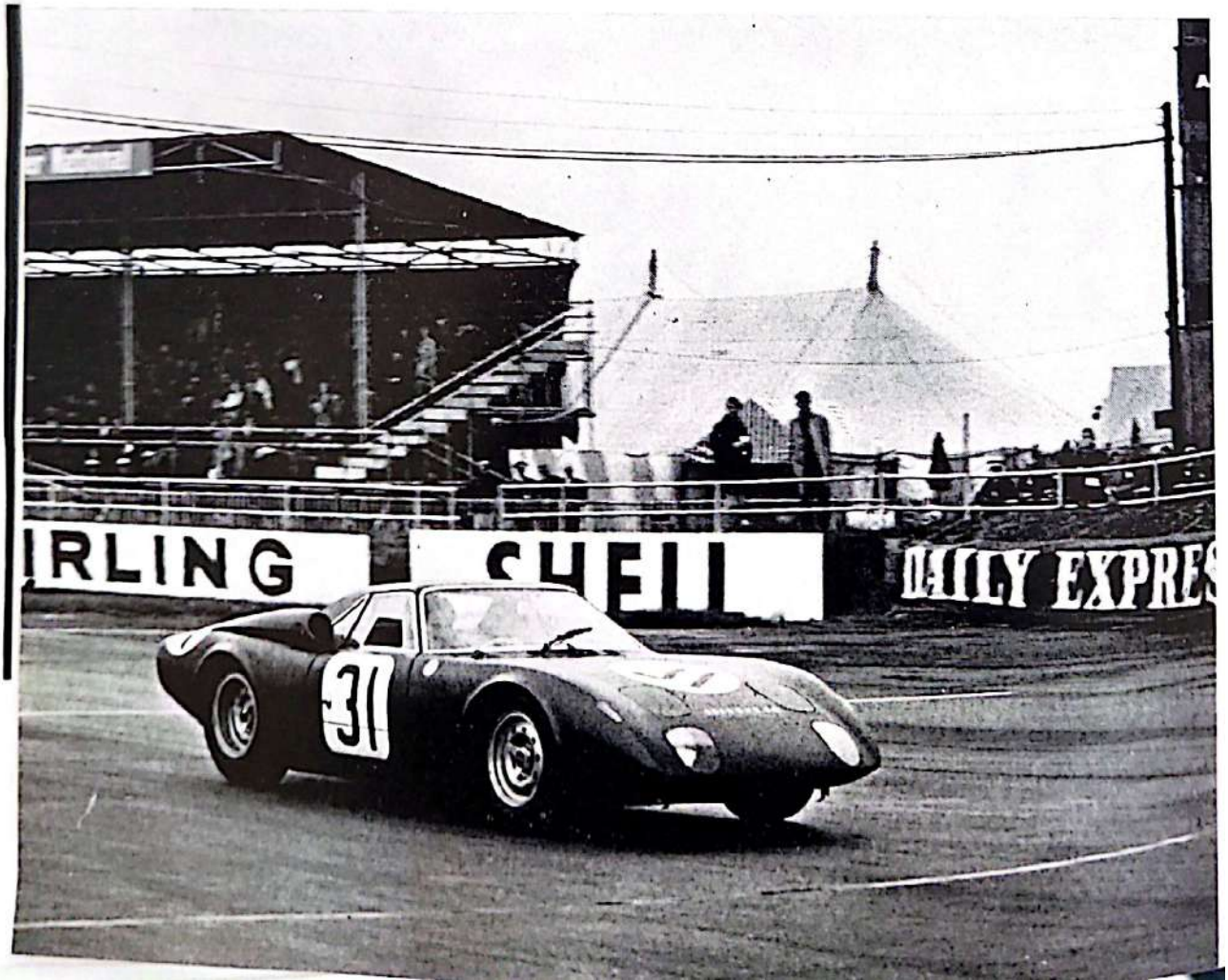
The time scale is also very different. From the decision to go ahead with a new model the automobile industry conventionally takes 4 or 5 years to the production stage. There is about 18 to 24 months to have a completely new Grand Prix car including engine and gear-box, performing in public. In the two-seater car classes there may be only a few months. As well as this, new versions of the car would be produced each year, for the several years which represents the life of a formula, which give substantial improvements in performance and are not just a "Detroit face-lift". Furthermore, one would expect to introduce improvements every few weeks as a result of experience in the field. The Automobile Industry, having produced a successful line of cars that is enjoying good sales may continue this line for a number of years: in motor racing the controlling body may decide that the formula, defining the type and size of car and engine, should be changed in the interest of the sport or furthering the policy that motor racing improves the breed of everyday cars. This means that where the manufacturer is developing a successful engine, he must bear in mind the regular changes of formula when planning long-term research programmes.

Life

In general, a total life of the main components of 10,000 miles is adequate as by this time the car will be obsolete relative to the competi-

FIG. 8. 1½-LITRE SUPERCHARGED B.R.M., 1952.

FIG. 9. 1965 ROVER-B.R.M. GAS TURBINE POWERED CAR.



tion. A chassis is inspected, crack-detected and serviced 10 or 20 times during this period. A body might last 5,000 miles with minor alterations. An average Grand Prix race meeting, including practising, involves about 500 miles and hence this is the minimum period between engine overhauls; a 1,000 miles is preferable but much longer means that it is not being driven fast enough. It is acceptable that some highly-stressed components, such as valve springs, will have a maximum life of 5 hours before being scrapped.

These mileages may seem small compared with the 50,000 mile or 5 year warranties of the U.S.A. automobile industry. It must be borne in mind that the cars are driven by the fastest men in the world and not by the "mythical old ladies of the second-hand car trade". This does, incidentally, give one advantage compared with industry: the men who test the cars are also the men who finally use them. Perhaps the biggest development problem in industry is that of relating the performance of test drivers to those of the public.

Pace of Development

An indication of the pace of development can be seen simply in fig. 10. This shows how the position of the racing driver in the B.R.M. racing cars has changed over the years. The need to go faster, to make the car smaller and to improve aerodynamics, has forced the designer to make the forward projected area of the driver smaller, and hence he has had to recline further back. In earlier B.R.M.s the seat was an independent part of the car and the driver had space all round his body. Currently, the seat is an integral part of the car and the cockpit is tailored with ergonomic principles to the individual driver's body and his leg and arm movements.

Appendix 3 shows the main characteristics of these cars. It will be seen how those factors which determine the performance of the car have improved through the years.

Manufacture and Administration

These are identical to any industrial production unit involving a

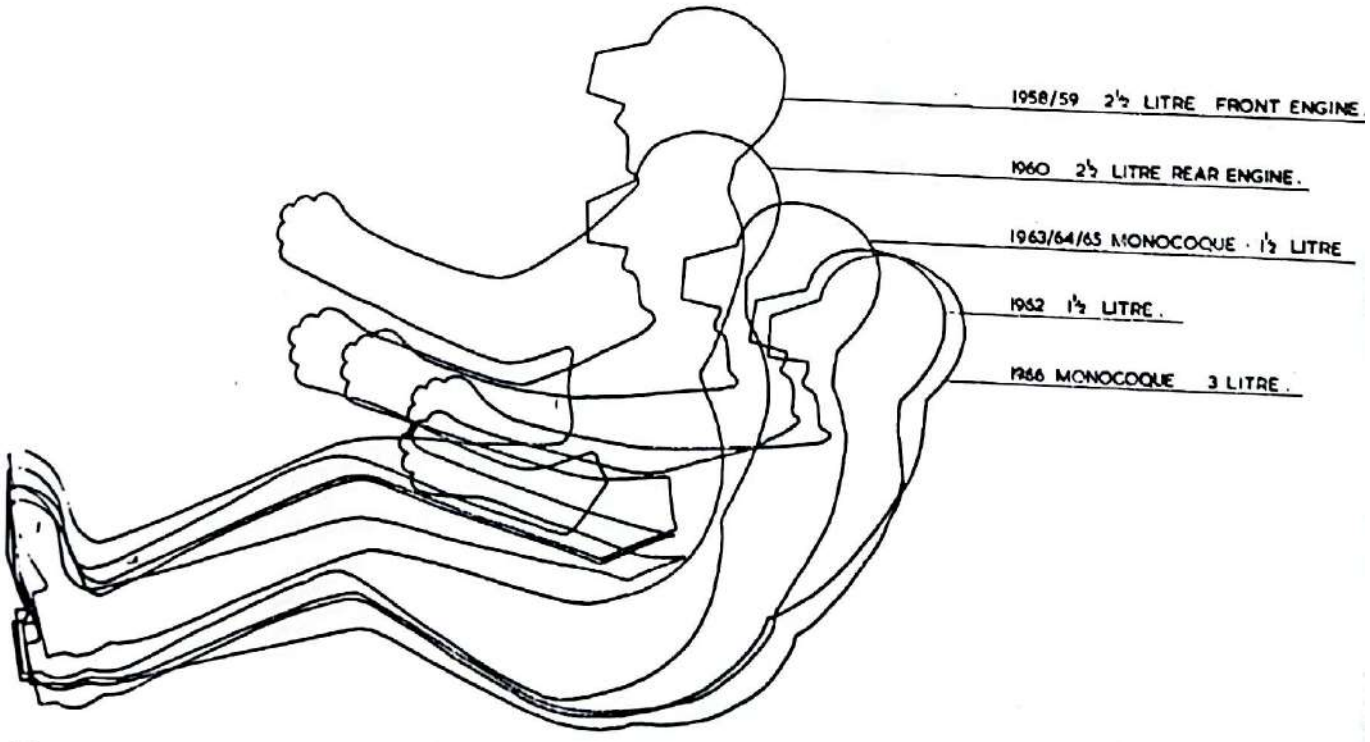


FIG. 10. DRIVER'S POSIT'ON IN B.R.M. FORMULA I CARS 1958—1966. THE PROFILE IS OF GRAHAM HILL.

similar number of personnel, with the advantage that they can readily appreciate the direct result of their activities.

Quantities

The first prototype of a new racing car, particularly a Grand Prix car, may well participate in a race and of a given model the constructor will probably only build 5 or 6, all of which will race and may indeed be sold afterwards. Industry can build more prototypes than the racing car constructors total production, to be tested by all and sundry.

Cost

Cost of manufacturing is not of prime importance and is always subservient to performance though the overall budget may at times force a compromise.

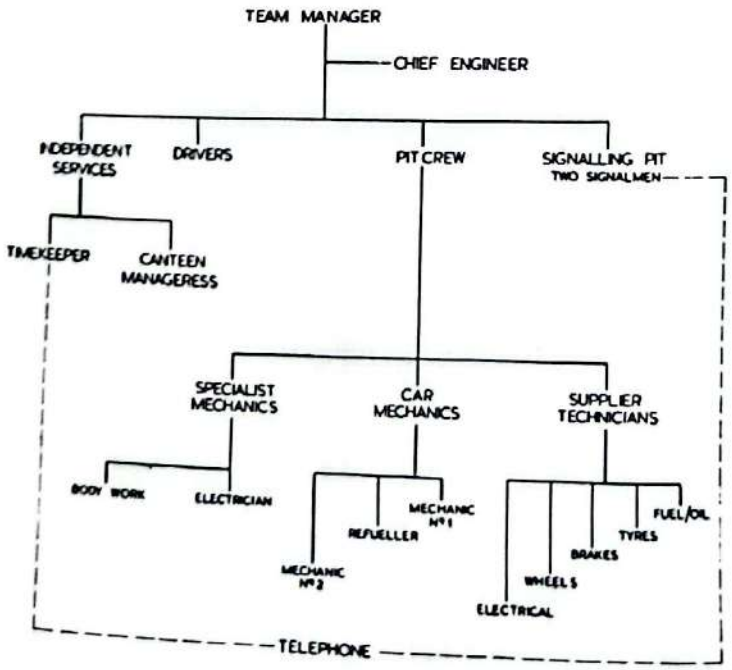
Public Interest

The solutions reached to motor racing research problems are immediately exposed to the critical gaze of a quarter of a million race spectators, the television viewers and both technical and popular press journalists. There are no sham bodies with next year's engine underneath. Racing research products are immediately exposed to the opposition and the performance compared in open competition.

4 RACE ORGANISATION

General

Races are won in the pits, just as much as on the track and organisation for the race is of vital importance. The planning and preparation of the team and its equipment, is a major operation independent of the technical problems associated with the racing cars. Planning of movements may be done months ahead. To illustrate the problems involved we can consider the entry of the Rover-B.R.M. (T) gas turbine car in the Le Mans 24-hour race in June, 1963, which concerned a team of people drawn from several companies under the leadership of Mr. W. "Wilkie" Wilkinson from the Owen Organisation. It should be explained that the car was competing for a special prize to be given to the first gas turbine powered car to complete the race at an average speed above 93.225 m.p.h. It was not in open competition.



The party was housed together in a hotel about 25 miles from the circuit. The drivers stayed at a separate hotel so that they could relax. The team's hotel gave a quiet atmosphere away from the "madding crowd" of the public and press, together with a large garage for their exclusive use.

Vehicles

The vehicles employed were:—

1. Land Rover towing articulated trailer carrying Rover-B.R.M.
2. Two cars for general transport.
3. Twelve-seater Land Rover for mechanics' transportation.
4. 14ft. "Sprite" caravan (mobile home) towed by 3 above.
5. The original B.R.M. mobile workshop, a special 7-ton truck, to carry all spares and provide working facilities at the circuit. It is equipped with welding facilities, lighting, power generator, benches, lockers, power tools, and the like.

The caravan consisted of a kitchen and a dining room that could be converted into a bedroom. It acted as a canteen for the team and drivers, a private office, and as sleeping quarters for the drivers throughout the race. It is important that the drivers should relax as much as possible and between stints, briefing, and meals, all their time was spent resting or sleeping. Similarly the pit team must be kept fully sustained from arrival on the circuit at 9.40 a.m. on Saturday, to 6.00 p.m. on Sunday. Hot soup in the early hours of the morning is as important a requisite as any car spare.

Personnel and Line Authority

The personnel can be grouped:

1. Team manager, the executive directly responsible for the working party, drivers instruction, and all negotiations and arrangements at the circuit. The line of command is shown on previous page.
2. Chief engineer, in particular responsible for technical decisions on the engine and advising technically from his detailed knowledge of the building of the car and engine.
3. Mechanics allowed on the track. The normal three were the refueler, mechanic 1 (engine), and mechanic 2 (chassis and suspension).
4. Two signallers. Signalling is done from a separate series of boxes near Mulsanne corner which is in telephone communication with the main pit. One signaller doubled as workshop driver and both were also responsible for the stores. This unit is completely independent of the main party and have their own food supplies and cooking facilities. They work without respite throughout the entire race.
5. Specialist mechanics, one for body work, and one electrician.
6. Independent specialists. Time-keeper and canteen manageress.
7. Technicians from supplier companies, in particular wheels, tyres, and brakes who are allowed to examine components on the car in the pit area and give advice. Any work must be carried out by mechanics 1 and 2.

One of the writers was present in an overall executive capacity to ensure smooth operation and to prevent outside interference disturbing the work.

Officially, the refueler may not touch the car but an experienced race trained mechanic was used since he could study the car for any possible damage. In an emergency any track mechanic may be replaced by a

specialist provided his feet have literally left the track and brassards are exchanged.

Minor Details

The details of organization includes many things which few people realize, such as:

1. The provision of brightly coloured (in our case orange) overalls for all mechanics. Apart from making them easily recognisable to officials and executives, this assists the driver to recognise his pit area as he enters it.

2. The provision for every mechanic of personal torches fastened to his overalls for night work.

3. Provision of other items of electrical equipment for working at night, making signals visible to the driver, and so on.

4. The provision of all spares suitably packed, identified and where necessary immediately available in the pits. Spares include such items as complete windscreen, complete engine and gear box, wheels fitted both with "wet weather" and "dry weather" tyres, down to the more mundane items of wire, nuts and bolts, spare material for bodywork, spare perspex covers, electrical equipment and fine extinguishers, to the gross weight of more than the car. Tools are available to do any job whatsoever on the car. Spares also include such items as sets of "bedded-in" brake pad linings.

Time Keeping

The time-keeper sits on the left hand side of the pit counter complete with all equipment and utterly oblivious of the rest of the team. With his stool, table, weather proofing equipment, lighting, watches, and lap charts, he works alone and uninterrupted, providing the team manager with the immediate race data he needs to plan his actions. The time-keeper, among other things, is responsible for keeping the team manager up to date with variations in lap times, current mean speeds, the position and danger of the opposition and the like.

Signalling Procedure

Lap times are signalled to the driver each lap and the last three laps of every stint were signalled so that he knew when to return to the pits. Position and any other information to interest the driver was also given.

Race Strategy

Calculations showed that to use the 47 gal. of the fuel capacity, which had been found in earlier tests to be the quantity readily available to the boost pumps, the Rover-B.R.M. could run for 2 hr 35 minutes between refuelings. Allowing for three minute pit stops we would have to run 2 hr 37 minutes to need only eight stops during the 24 hr. It was, therefore, decided to allow for nine pit stops and to avoid being embarrassed by possible differences in fuel consumption during the race compared with trials: 2 hr 25 minutes was chosen for the first stint. In a 24 hr race the best times of official practices can never be achieved as a race average. Best practice laps had been of the order of 4 minutes 22 sec.

It was decided to let the drivers "run their own race" being as fast as possible consistent with safety. There was no point in impeding faster cars which were endeavouring to be first in the overall classification.

Pre-Race Preparation

The whole of the day before the race was available for pre-race preparation. This involved :

1. Certain minor alterations following the last practice session, such as alterations to the accelerator pedal to satisfy both drivers.

2. Detailed flow checks on boost pumps and careful examination.

3. Fitting new perspex headlamp covers, sealing trim, touching up paint.

4. Detailed examination of body and chassis for possible cracks, of which none were found.

5. Slackening of front and rear body fittings and various other adjustments to assist rapid pit work.

6. All battery connections between cells were soldered as a means of locking.

7. Run engine for two minutes to check for fuel and oil leaks. Check security of all fastenings.

8. Standard B.R.M. check list procedure on all chassis details, checking tightening torques, greasing, wiring and so on.

9. Final training of mechanics in pit stop procedure including wheel and brake pad changing.

10. Final polish of car and packing of all equipment ready for the morning.

Start of Race

The race started at 4.00 p.m. At 3.40 p.m., the Rover-B.R.M. was pushed up the line of the pits to the official starting place in the middle of the track, pointing in the direction of the race and "up-stream" of all the cars arranged in the official Le Mans formation. An official starter was allocated to this car only. The engine was started as the flag dropped for the race and the engine left idling until the Rover-B.R.M. flag was dropped when all other cars had safely departed. This was at 4.00 p.m. plus 37.4 sec. This time was allowed in the official calculations for the proportion of the last lap.

Pit Stop Procedure

In following the procedure, the following points should be noted:

1. Oil and fuel tanks are sealed with pieces of wire ending in special lead tags. These are fitted by an official "plombeur" and must not be touched by any member of the team.

2. The portion of the track in front of the pit sloped upwards in the direction of the race 1 in. in 50 in. Since the fuel filler is at the back of the tanks, this would mean that the tanks could be about 5 gal. short when filling. It was, therefore, necessary to jack up the back of the car during refueling to ensure complete filling.

The procedure adopted at each pit stop was:

(a) Mechanic 1, with L/H air filter in hand, flags down the car to the correct position and opens L/H door for the driver.

(b) Driver leaps out and informs chief engineer if ammeter shows satisfactory low charge and then briefs the second driver, informing him of car characteristics, danger on the track, etc. (The ammeter reading was important as it indicated the state of the alternator belt and battery and whether any attention was required).

(c) Mechanic 2, holding R/H air filter raises the tail and the plombeur breaks fuel seal. Refueler starts filling.

(d) Mechanic 2 jacks up the back of the car and changes R/H air filter.

(e) Mechanic 1, having already fitted the L/H filter, checks engine oil level. (If this needs topping up he calls plombeur to break seal, adds whatever oil is necessary with a quick fill gun known as "hypodermic," and the plombeur reseals).

(f) Mechanic 2 checks gear box oil level from sight gage, adding where necessary as (e), checks temperature and inspects rear brake pads and tyres.

(g) Mechanic 1 inspects front tyres and brake pads and cleans windscreen.

(h) Plombeur seals fuel filler cap, mechanic 2 drops car off jack and closes the tail and mechanic 1 closes the L/H door on the second driver who has already entered.

(i) Driver presses starter as door closes and leaves on instructions of Pit Marshal.

(j) Previous driver informs chief engineer of instrument readings and car behaviour.

At the last pit stop before the end of the race all electrical components are checked since these can be scrutineered after the race if the officials desire.

Results

The car completed the required distance under the award conditions with 3-1/4 hr to spare and at this point it was theoretically only necessary to complete the last lap, between 3.40 and 4.00 p.m., within 20 minutes. The official result was an average speed of 173.546 kph (107.833 mph) compared with the target of 150 kph (93.225 mph).

The car was not classified officially but lap charts were maintained giving its position as if it had been classified to compare with other cars. By the end of the sixth hour the Rover-B.R.M. was unofficially 19th and by the end of the 12th hour, 9th. If the rate of cars falling out had been maintained, there was the embarrassing prospect that it might have contested the leader. As it was, if classified, it would have been 8th.

Speculation is dangerous and misleading. A number of internal combustion engine cars of the 2-litre class were faster in terms of average lap speed both in practice and the race, compared with the Rover-B.R.M. For example, the Porsche, No. 27, had an average speed of 114 mph for the first 12 hr compared with 108 mph for the Rover-B.R.M., but had an accident outside the driver's control. The Porsche No. 28 had an average speed of 110 mph for the first 12 hr but lost a wheel and was delayed 1 hr. One interesting observation relates to the A.C. Cobra, No. 3, a British entry though American engine powered. This completed 4171.160 kilometers at an average speed of 173.798 kph compared with the Rover-B.R.M. 4172.910 kilometers at an average speed of 173.546 kph. (The apparent discrepancy is due to the official method of calculating the distance completed during the last lap when the 24 hr. exactly is finished). The A.C. Cobra was ailing and had been slowing down for some time. There was no observable drop in performance on the Rover-B.R.M. and if it were to be classified the team manager would have undoubtedly arranged with the drivers to overtake.

Statistically, the most interesting result of the Rover-B.R.M. is the consistent lap time, with both drivers. It was extended a little during the early hours of the morning due to mist and an obvious increase in lap time occurred for a few laps when there was a shower of rain in the early afternoon of the second day lifting the oil on the track. The probable reasons for this are:

1. The chassis and suspension had been proved under Grand Prix racing conditions.

2. The gas turbine, with its relative freedom from vibration gives far less fatigue to the car components than an I.C. engine.

3. The extremely high ability and experience of the drivers, one of whom was World Champion.

4. The race was against the clock and not other competitors; hence, there was not the urge to go that fraction faster nor to risk overtaking the car in front under possibly dangerous circumstances.

5. It is interesting that there was no car within ± 10 sec of the practice time of the Rover-B.R.M., and hence it was not constantly "dicing" with other cars of comparable performance.

6. A fair share of luck. Many cars fail at Le Mans through no fault of their own, but because of a certain drop of oil on the track, an accident leaving debris, or the like. Although the drivers' skill was paramount, luck played a part.

5. TESTING

Basic Philosophy

Testing falls into two main groups — that for research to improve the product, or routine testing to ensure that standards are being maintained. In practice, there is no hard and fast line of demarcation. Due to the small number of components involved, it is frequently more practical to use an engine undergoing routine proof testing prior to a race, to carry out a minor research experiment, or to try a new type of tyre compound in practice prior to a major race.

Testing as a part of motor racing research has two important differences from normal research. Since motor racing is concerned with extracting the ultimate in performance from every component, it follows that a great number of tests will prove unsucccessful. This frequently has a demoralising effect on research personnel. Secondly, due to the small number of units involved or available, at the best probably only six, it is frequently impossible to carry out the normal research technique of either running a number of tests in parallel, and averaging the results, or repeating the same test many times to ensure that the result gives a true indication. It is particularly necessary also to ensure that no complicating extraneous circumstances are affecting the results—for example, in 1956, on the 2½-litre 4-cylinder engine, a drastic reduction in compression ratio was tried, which gave a dramatic improvement in mid-range torque. When applied to the remaining four engines of the same type, no such improvement was recorded and in three cases there was a distinct loss in power throughout the range. It was over a year before it was discovered that the first engine used had freak inlet port conditions, which produced abnormal turbulence and hence the gain in power when the test was carried out.

The essential principle that must be followed is never carry out two tests simultaneously. Obviously one would not try a different tyre tread pattern with a different road spring, as it is impossible to determine the value of either. With the extreme urgency of motor racing, it is frequently tempting to try two improvements at once and accept the gain in performance which results. This, however, must be rigidly avoided as the time comes when some development of the original component is being planned and it is not known which range previously made produced the essential and vital improvement.

This is defined as testing of the engine carried out away from the car and can be further sub-divided into two sections. The rig testing

of engine components, such as oil and water pumps, the air flow evaluation of cylinder heads, etc., and the dynamic testing of the complete engine on the test bed. Obviously this is not the end of engine testing, which is also carried out on roller dynamometers and installed in the actual racing car on the track.

Engine Testing

Although the dynamometer is the essential tool for this, there are many other pieces of equipment which are equally as important, including the indicator, etc. It is worth noting that there must be some connection between the Japanese successes in the small high-speed engine field and their successful application of miniaturising techniques to electronic equipment, which can be used for obtaining engine performance data. As the research involved in racing engines almost invariably means breaking new ground, it frequently follows that the first step in the research programme is to evolve the piece of equipment necessary to obtain the required data. This even applies to dynamometers. Unlike production testing, the most essential characteristic of a racing engine research dynamometer is its ability to hold a constant speed with wide variations of torque. When seeking new equipment recently the only dynamometers available in the 15,000 r.p.m. range were those intended for turbo prop aero engine testing. Final development of the modified dynamometer was carried out in parallel with development of the engine.

Another of the problems of racing engine development is that considerable gains can be made by the full exploitation of harmonic exhaust systems. This can only be done if the exhaust system is used in the unsilenced condition. The Rubery Owen Engine Development Division are fortunate in having their engine test facilities situated nearly 2 miles from the nearest human habitation. With the engine exhaust being discharged into the test house, ventilation poses a considerable problem, particularly if consistent results are to be obtained. This has been overcome by the use of small Government surplus aero engines, complete with their propellors.

When the prototype of a new engine is first fitted to the dynamometer, it may run for several hours, being motored round by a slave engine before it is started under its own power. Critical evaluations are made of oil and water flows, together with fuel flows and injection spray patterns, before the engine is actually started. This caution is frequently a result of the limited number of units available, and the essential need to preserve the prototype engine as long as possible. With modern machining and finish techniques, running-in is largely a formality; and after the engine has been warmed up, it is run for a limited period under load up to say half its designed r.p.m. It is then removed from the dynamometer and stripped for examination, the intention being to detect signs of incipient failure or other troubles. Such faults that are found are rectified, the engine re-assembled, returned to the test bed and run again at slightly higher r.p.m. — the cycle being repeated until at last the engine has been run at maximum r.p.m.

During these tests water flow has already been measured by the use of Venturi type flowmeters in the test bed system, and a good idea obtained of heat rejected to water by means of thermometers across various points of the water system.

Oil flows and heat rejection to oil are measured simultaneously, again by resort to the bucket and stop watch. The scavenge oil is piped into a container with a quick release valve in its base; this

container is suspended from a spring balance. The oil temperature rise across the engine is recorded, together with the weight of oil flowing from the engine in unit time. Where possible, the quantity of oil flowing to the various accessories, such as camshafts, is measured either by Venturi type flowmeters or by recovering the return oil. Experiments are conducted to determine the optimum proportions of inlet tract and fuel flow requirements, together with similar experiments on the exhaust system. Ideally, every variation in induction system characteristic should be tested against every variation in exhaust system characteristic, since one influences the other. Here the use of a remote control for the Vernier adjustment of the fuel injection unit is of considerable advantage. The one in use at the Rubery Owen Engine Development Division consists of a lorry speedometer drive cable. Experienced testers, however, can quickly recognise the areas of investigation which are unprofitable, and match say five induction variables with five exhaust system variables, instead of 25 inlet variables against 25 exhaust variables. This saves a considerable amount of time.

When the engine has been brought to the peak of its "tune", data can be collected from it to enable the designers and development engineers to determine the future steps. These involved tests to determine what are known as the three 'Es' — these are, Mechanical Efficiency, Air Efficiency and Combustion Efficiency. The heat rejected to oil gives some indication of mechanical efficiency; but, in conjunction with Shell, a simple piece of equipment which permits a test, which is a refinement of the old Morse test, has been developed; in the Morse test one cylinder was cut out by removing the plug lead for a long period, which of course brought in its train a number of errors, due to temperature changes in the cylinder — loss of exhaust harmonic effect, etc. This simple piece of equipment which has been devised, is a refinement of the original test — the equipment is attached to and driven by the distributor. This equipment eliminates one spark either per cycle or per 10 cycles, or per 100 cycles, in the firing sequence of the engine. It, therefore, avoids the destructive effects of the Morse tests through running the engine with one cylinder out over long periods, and retains the influence of the induction and exhaust harmonics, and there are virtually no temperature changes.

Some idea of the engine's air efficiency can have been gained by the shape of the power curve and the specific fuel consumption. The actual quantity of air being consumed by the engine can be measured with a Viscovs type flowmeter. Care has to be taken that the size of the flowmeter is such that there is no significant reduction in power output of the engine under test.

Finally, the combustion interval is measured by a piece of equipment, again devised by Shell, known as a Combustion Interval Meter. It measures the time it takes the flame front to advance on the sparking plug, to a probe within the cylinder. A full cylinder pressure diagram is then taken, including the induction stroke; and from this information the development engineers are then able to determine which is the most profitable field for immediate development. In parallel with this testing, further testing is also being carried out to eliminate mechanical weaknesses and defects. It is necessary to analyse and condense all the data obtained from these tests and present it to the racing team, who will operate this engine, in simple and condensed form, so that it may be used for fault diagnosis, etc., in the field. A simple solution is to take one of the senior testers to each motor race.

After this, testing becomes a little more sophisticated, including the use of sparking plugs fitted with thermo-couples, voltage required by

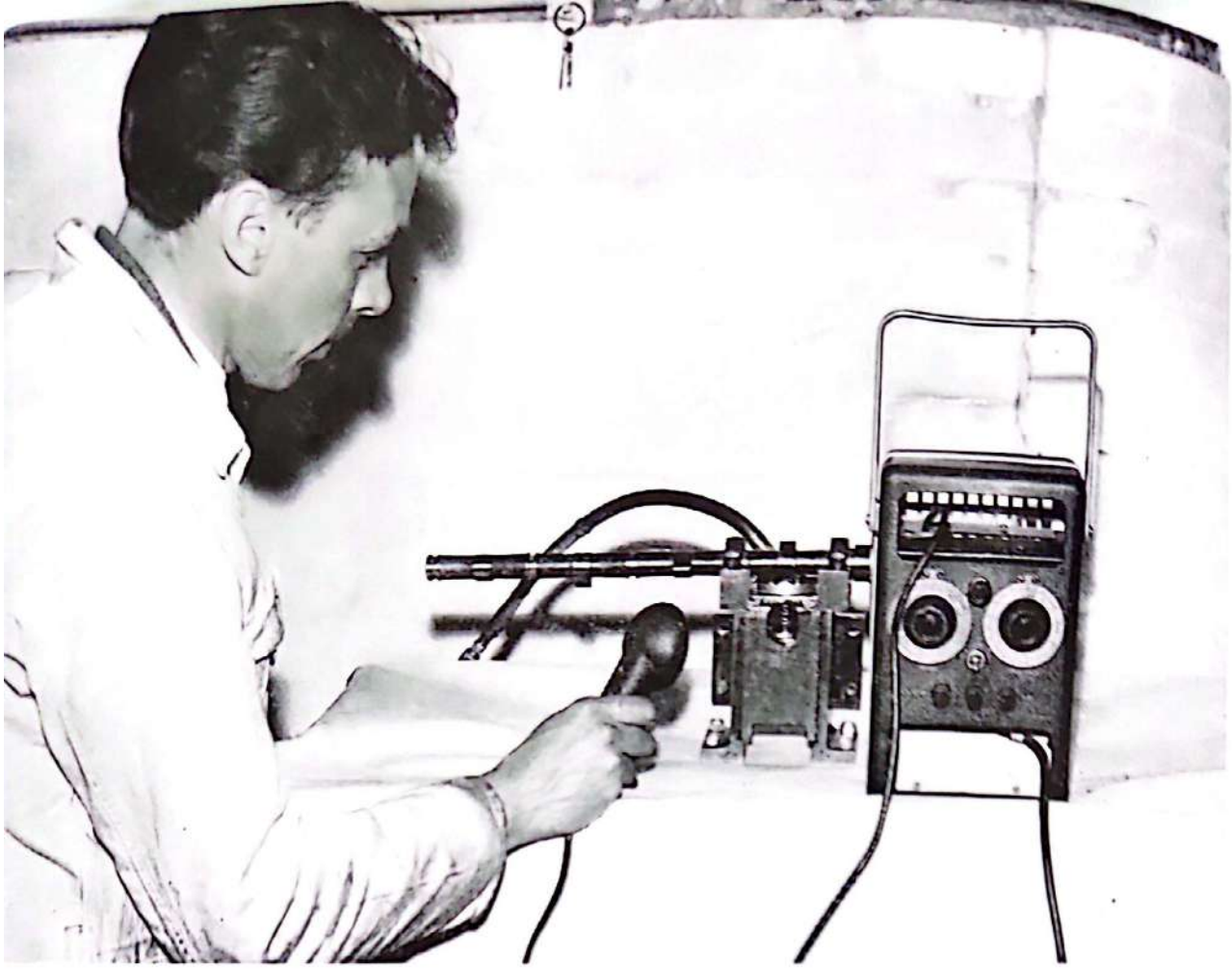
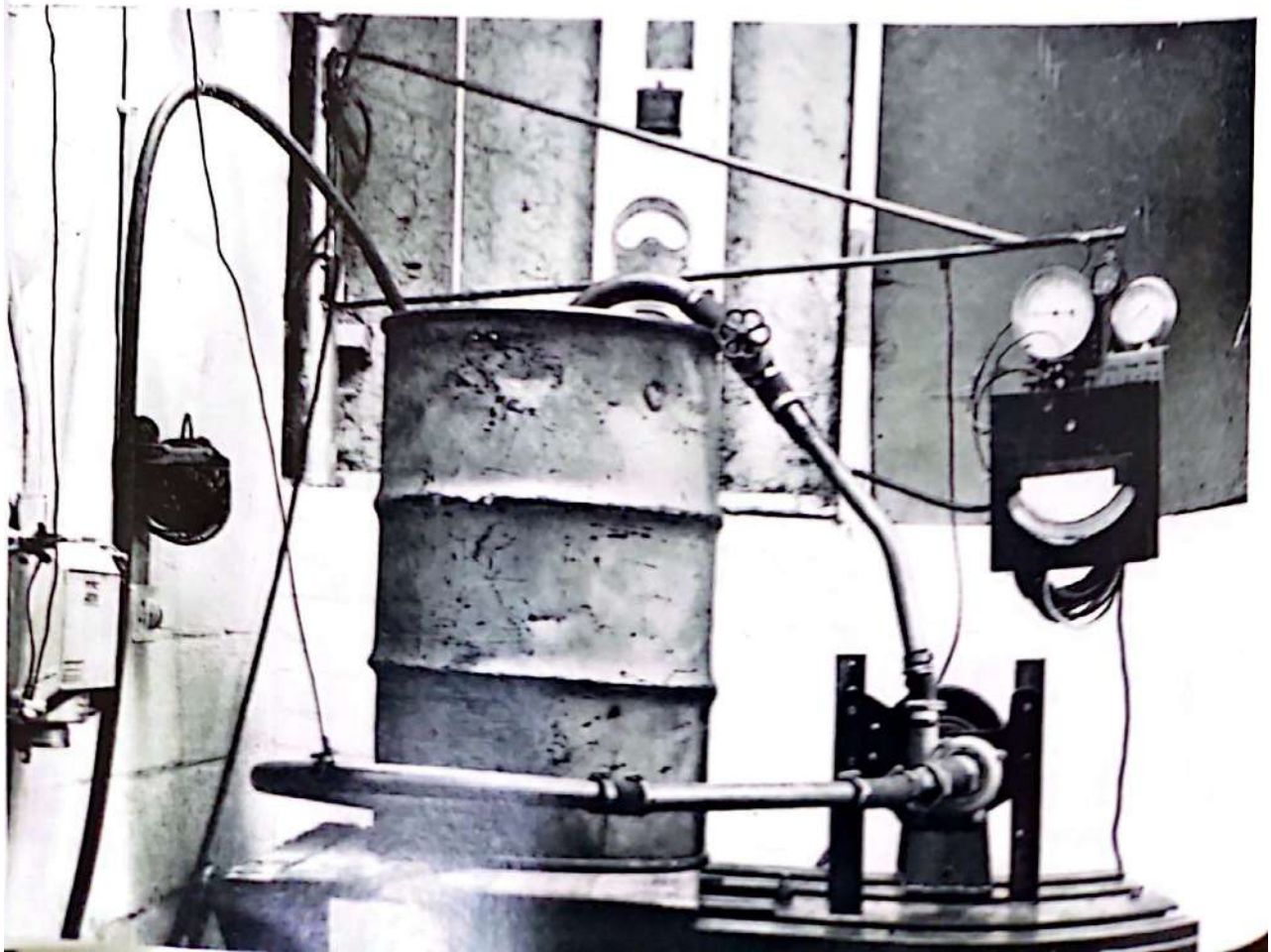


FIG. 11. TESTING VALVE GEAR AT HIGH SPEED UNDER STROBOSCOPIC EXAMINATION.

FIG. 12. RIG TESTING OF A WATER CIRCULATION PUMP.



the sparking plugs, etc., can all be measured. Variations in valve timing and camshaft characteristics will be suggested by the air efficiency tests and indicator diagrams. When such a change is made, before it can be rejected as not effective, it is necessary to go through the range of inlet and exhaust system characteristics again, probably ignition and fuel injection characteristics also. This development testing becomes a continuous process and it must be laboriously thorough if it is to yield results. As an illustration, work on the air flow rig recently indicated that a change in the size and shape of exhaust valve would substantially improve the exhaust flow. When these valves were fitted to the engine, no improvement was recorded. Similarly, improvements to the inlet valve seat and shape of the inlet port indicated that there was a gain in inlet flow. When these improvements were applied to the main engine there was no gain in performance. The two improvements were, therefore, applied together, it being reasoned that the inlet port improvements would permit more air to enter the cylinder, and the exhaust valve improvements would facilitate its departure. Again, the results were disappointing.

Meanwhile tests were being carried out on a different shape of combustion chamber. Although this showed an increase in flame travel speed, there was no corresponding increase in horsepower. When, however, the new combustion chamber was combined with the modified valve seats and the new exhaust valves, there was a considerable increase in horsepower; and the shape of the power curve was altered to an extent that it indicated that if the engine could be turned at 12,000 r.p.m. instead of 11,000, there would be an even further increase in power. The research emphasis was then concentrated on the mechanical problems, to permit the engine to be run at 12,000 r.p.m. and here recourse had to be made to the test rig for camshafts and valve springs.

Despite the extensive use of the most modern sophisticated equipment, it is still significant that an experienced tester can sense an engine characteristic on occasions far more rapidly than the electronic gear; and although the sophisticated equipment will give height, depth, breadth and colour to the problem, it is frequently the tester's expertise which determines what the problem is and which piece of equipment shall be applied to solve the problem.

Rig Testing

The basic piece of equipment for this consists either of an old machine bed-plate, or a similar structure, which carries a variable speed electric motor. Experience shows that the less sophisticated the rig the more versatile, and the most accurate and widely used piece of ancillary equipment used on these rigs is invariably the bucket and stop watch, which is still the most accurate and reliable flow-meter yet devised. In the majority of cases where the unit under test is a pump of some sort, some means of heating and cooling the fluid in use also has to be provided. The illustrations 11 and 12 show the test rig in use, testing a pressure oil pump with back pressure applied and the oil temperature raised to the working level of 80 deg. C. a complete scavenge pump unit being tested for recovery under surge conditions, where one of the inlets has been uncovered: Fig. 11—the rig testing of valve gear at high speeds under stroboscopic examination and Fig. 12—the testing of a water circulation pump.

Rig testing of pumps generally begins with the prototype pump, which is tested against a schedule produced by the Design Office. This establishes that the pump produces its design performance and may bring in its train minor mechanical problems — for example, oil pressure

in an oil pump may move hydraulic bearing bushes out of position. These tests are followed by a second series, which are intended to establish the production tolerances — that is, what degree of end float increase through wear may be permitted, etc. The pump may be tested under adverse conditions; it is obviously desirable to know how long an oil pump will take to re-prime when it has been air locked under such conditions as may exist, when the car swings round a corner with the oil level low in the tank.

After initial testing, water pumps are submitted to a series of tests at varying water inlet temperatures and inlet pressures, together with different restrictions on the outlet.

The results are then plotted graphically, which give a series of grids, from which the behaviour of the pump under any combination of conditions may be determined. It will be found that one shape of water pump impellor gives extremely good results when operating under extreme conditions of pressure difference, yet this same impellor is useless when it is required to pump a mixture of water, steam and air bubbles. From this, tests are obviously required of the complete water system, to determine the relative desirability of using pumps with impellors, which are capable of pumping steam, compared with pumps which have impellors which are incapable of pumping steam, used in conjunction with a steam separating water system.

These rig tests are then repeated with the pump fitted in place on the main engine carcase. It is frequently found that oil pumps drawing through the most complicated inlet passages cast in the crankcase, suffer no restriction, while under other circumstances, pumps drawing through quite simple passages will suffer serious restriction.

It is the Rubery Owen Engine Development Division's practice to not only rig test the prototype of a new pump, but to rig test every new pump built, and every pump that has been subjected to a major overhaul, before this component is fitted to its engine. The rig testing of camshaft and valve gear appears to be one of the lesser used poppet valve engine research techniques. This is surprising as there are a number of high-performance engines, as distinct from racing engines, in existence today, where the clearances between valves and pistons are such that if one gets out of phase with another there is a disastrous mechanical entanglement—therefore if the behaviour of the valve gear can be studied at leisure on a test rig, many mechanical disasters can be avoided. Valve gear rig testing can be divided into several minor headings, including wear resistance, mechanical reliability of components, the ability of the valve to follow the path required by the camshaft, lubrication, etc. On a racing engine more than any other, the usual engineering conflicts arise where one has to make a compromise between the materials which give the best wear resistance, and the materials which give the best mechanical strength. It is of interest to note that a heat treatment technique developed in conjunction with the Shell Oil Company to increase wear resistance of the tappet was also found on the test rig to have slightly increased its mechanical strength. As a result of development work on this particular test rig, this heat treatment process was perfected and is now in use by major Motor Car Manufacturers. The Stroboscope or Stroboflood lamp is an essential tool for use in conjunction with this test rig; the high speed camera has been used with great success in its application. It is generally necessary to interpose some sort of spinning plastic disc between the camera lens and the valve gear under test to prevent it becoming obscured by lubricating oil. An accelerated failure test technique has also been devised, which can produce a service failure which normally occurred after 350 to 500 miles, in around 40/60 seconds. Use of this test technique even-

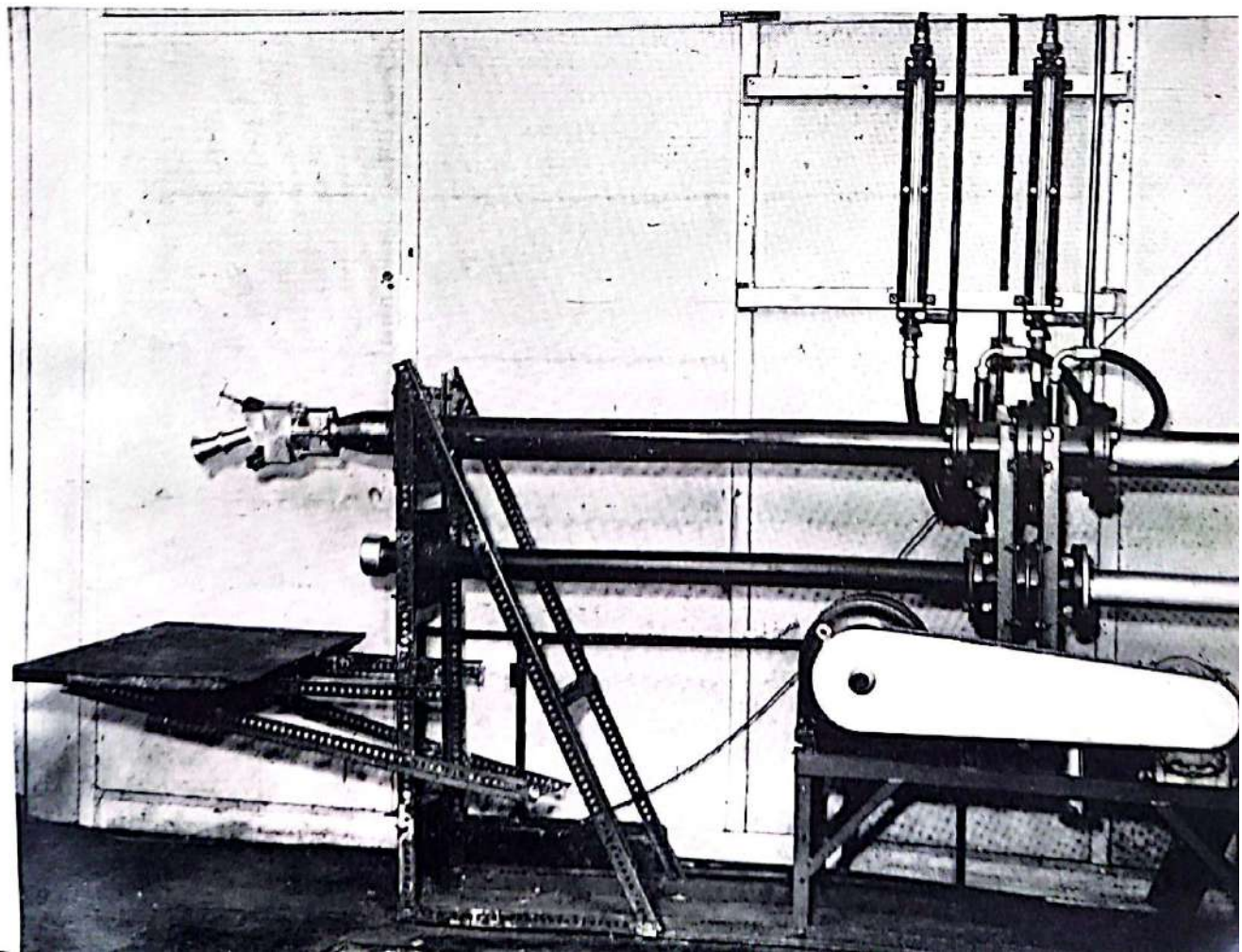
tually resulted in the choice of materials for the camshaft and tappet which had a rig test life of 15 minutes, and a racing life of several thousand miles. This technique also helped to find the solution to another problem, which was that if a camshaft was made sufficiently hard to avoid wear, it became too brittle and suffered impact fractures.

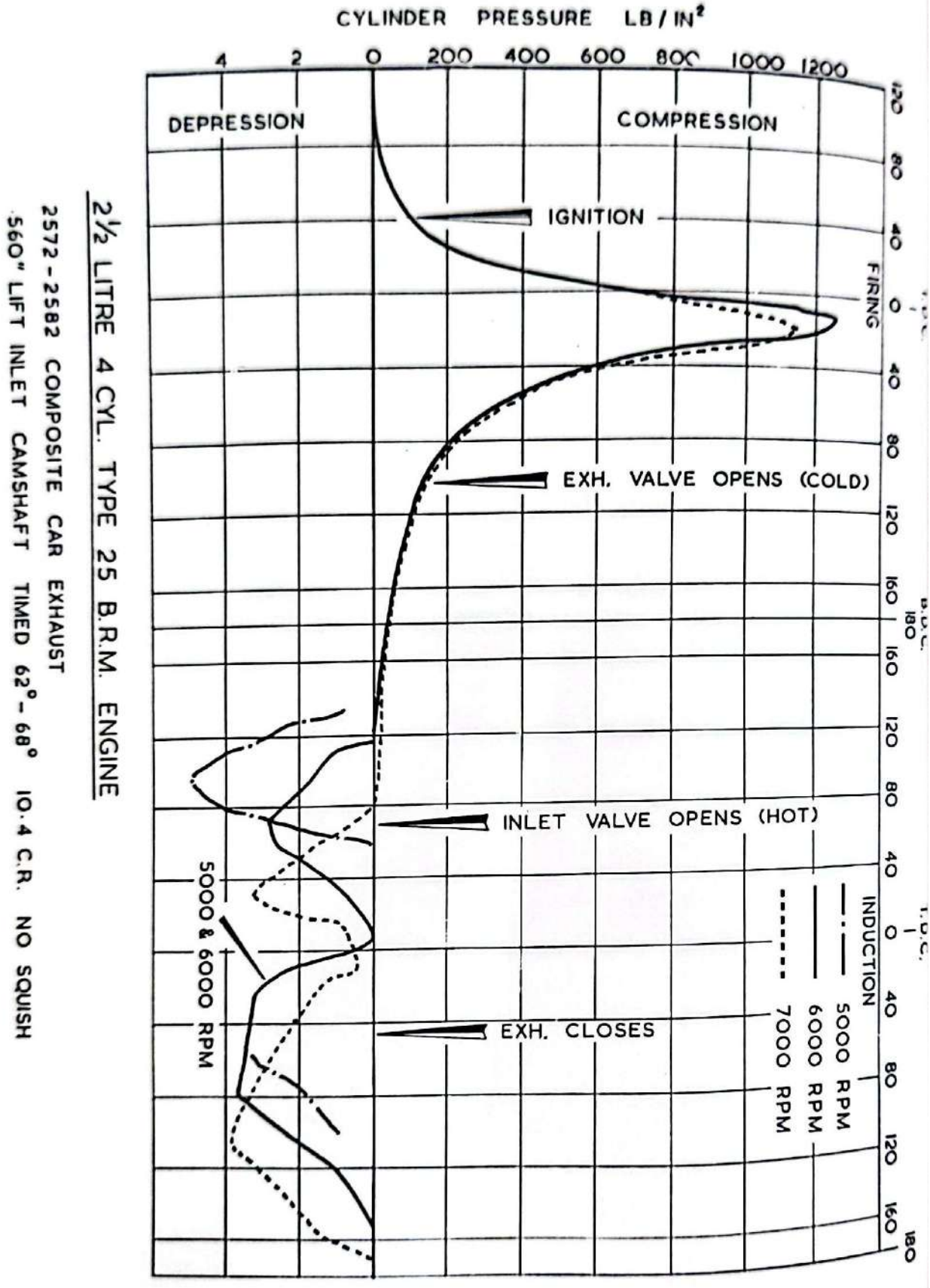
Oil flow patterns could also be observed and the minimum volume of oil necessary to avoid wear or seizure determined, as obviously it is undesirable to have an excess of oil circulating in the rocker box. It was also found that if the tappet could be persuaded to rotate, wear was reduced, and the amount of lubricant required also reduced. The means to initiate this rotation was discovered on the test rig and also the amount of rotation necessary to avert wear was also established. It was possible too, using the stroboscopic techniques, to examine the frequencies at which valve springs surge occurred; and by simple detail modifications to eliminate these. The result of this camshaft testing was such that the first eight V-8 racing engines had accumulated 37,000 racing miles between them before valvegear failure occurred.

Flow Rigs

The most widely used and misused piece of equipment here is the air flow test rig (Fig. 13). This consists essentially of a very long tube of approximately the same bore as the cylinder of the engine under test. A B.S.I. standard orifice plate, a rotometer type air flow meter set across the orifice plate and calibrated in cubic feet of air per minute; an air reservoir of sufficient capacity to damp out most pulses due to the action of the suction-pump — the suction pump itself; some sort of air bleed to vary the pressure difference across the rig, and a water manometer which indicates the pressure difference across the rig. The cylinder

GENERAL VIEW OF AIR FLOW RIG UPPER SECTION FOR ENGINES 3" BORE AND ABOVE LOWER SECTION FOR ENGINES LESS THAN 3" BORE. VERTICAL TUBES ARE FLOWMETERS CALIBRATED IN CUBIC FEET OF AIR PER MINUTES FLOWING THROUGH ORIFICE PLATES. UPPER TUBE IS FITTED WITH MODEL HEAD AND SWIRL INDICATOR.





2½ LITRE 4 CYL. TYPE 25 B.R.M. ENGINE

2572 - 2582 COMPOSITE CAR EXHAUST

·560" LIFT INLET CAMSHAFT TIMED 62° - 68° 10·4 C.R. NO SQUISH

FIG. 14

head or particular port under test, is then fitted by means of suitable adaptors to the rig, and air is drawn through the inlet valve by the suction pump at a predetermined depression. The valve lift is varied by means of various clamps or in the Rubery Owen Engine Development Division's case, by the use of a mircometer thread. Obviously, variations of port shape or valve shape at the same lift will produce different flows; and in theory, but not in practice, the greater the air flow the greater the performance of the engine.

Work by the Massachusetts Institute of Technology (J and K) made clear the limitations of the air flow rig as an aid to increasing engine performance, and the term "gulp" factor, which first appeared in these papers, really illustrates that the authors were aware of the limitations of the air flow rig. It is obvious that the air flow rig produces a steady state of flow, where in the engine the flow is anything but a steady state.

In the case of the inlet valve, the primary factor which causes air flow through the open valve is movement of the piston. There is a secondary and less obvious factor — that is, the effect of harmonic induction and exhaust systems. This is best illustrated by graph Fig. 14— this shows a cylinder pressure diagram for the complete cycle of a 2½-litre 4-cylinder engine, with exhaust stubs and with a harmonic exhaust system. The negative pressure effect before top dead centre approaching the induction stroke on the harmonic exhaust system will be clearly seen; and it will be obvious that this will greatly assist the flow of air into the cylinder, even though the piston is still rising and opposing the entry of the air. Using the cylinder pressures from this test, which incidentally took over a week to complete, the inlet port was flowed at the depressions and valve lifts pertaining at various crank angles. A truer picture of the inlet flow was obtained and adjustments were made to the valve timing, which included a reduction in inlet valve lift from .6″ to .5″. There was as a result a 3% increase in power and a considerable increase in valve gear reliability.

The second, less obvious, but more widely appreciated limitation of the air flow test rig, and one incidentally which can be overcome, is that for good combustion characteristics, most engines demand some degree of turbulence. One way of achieving this is by means of port or valve induced swirl; however, if the direction of motion of the incoming air is changed, some of its energy is lost, and the volume flowed is less as a general rule. Clearly, some means of evaluating swirl in conjunction with a port was required.

Using published data (J & K), Reference Swirl Indicators of various sizes were constructed — Fig. 15. These consist essentially of a free rotating vane in a plastic tube. The presence and amount of swirl can be related to the speed of rotation of the vane. It is obviously desirable to obtain maximum air flow with some swirl, but only engine testing will show how little swirl can be tolerated.

With carburettor and some injection engines, an excess of swirl can be undesirable as centrifugal effects lead to the heavy fuel being deposited on the cylinder walls, or at least the charge density varying across the cylinder bore with the heavier fuel on the outside furthest away from the centrally located sparking plug common on high performance engines.

The flow rig is also used for evaluating exhaust ports and it also gives useful results here, although again its limitations should be borne in mind, that the rig is generally operating at small depressions in the

order of a quarter of a pound per square inch, where the exhaust port is operating at positive pressures anywhere up to 100 lbs. per square inch. Further, the post is operating on air at room temperature, whereas in practice it is operating on exhaust gas at temperatures anywhere between 250 and 600 deg. C. In the case of prototype testing, the effect of the piston crown on air flow is also measured; this is done by plugging up the exhaust guide and flowing the inlet port via the wide open exhaust port. Appropriate valve lifts relative to the piston position, which is varied either side of Top Dead Centre, are employed and the effect of air flow around the valve cut-outs in the piston crown, etc., can be evaluated. It is particularly important, of course, to be aware in advance of the free flow of the unobstructed exhaust port.

These are all pure research techniques. The Rubery Owen Engine Development Division however make a practice of air flowing on the rig every port in every new or re-conditioned cylinder head before it is fitted to an engine. It has been found by bitter experience that two apparently identical ports in appearance and dimensionally can give

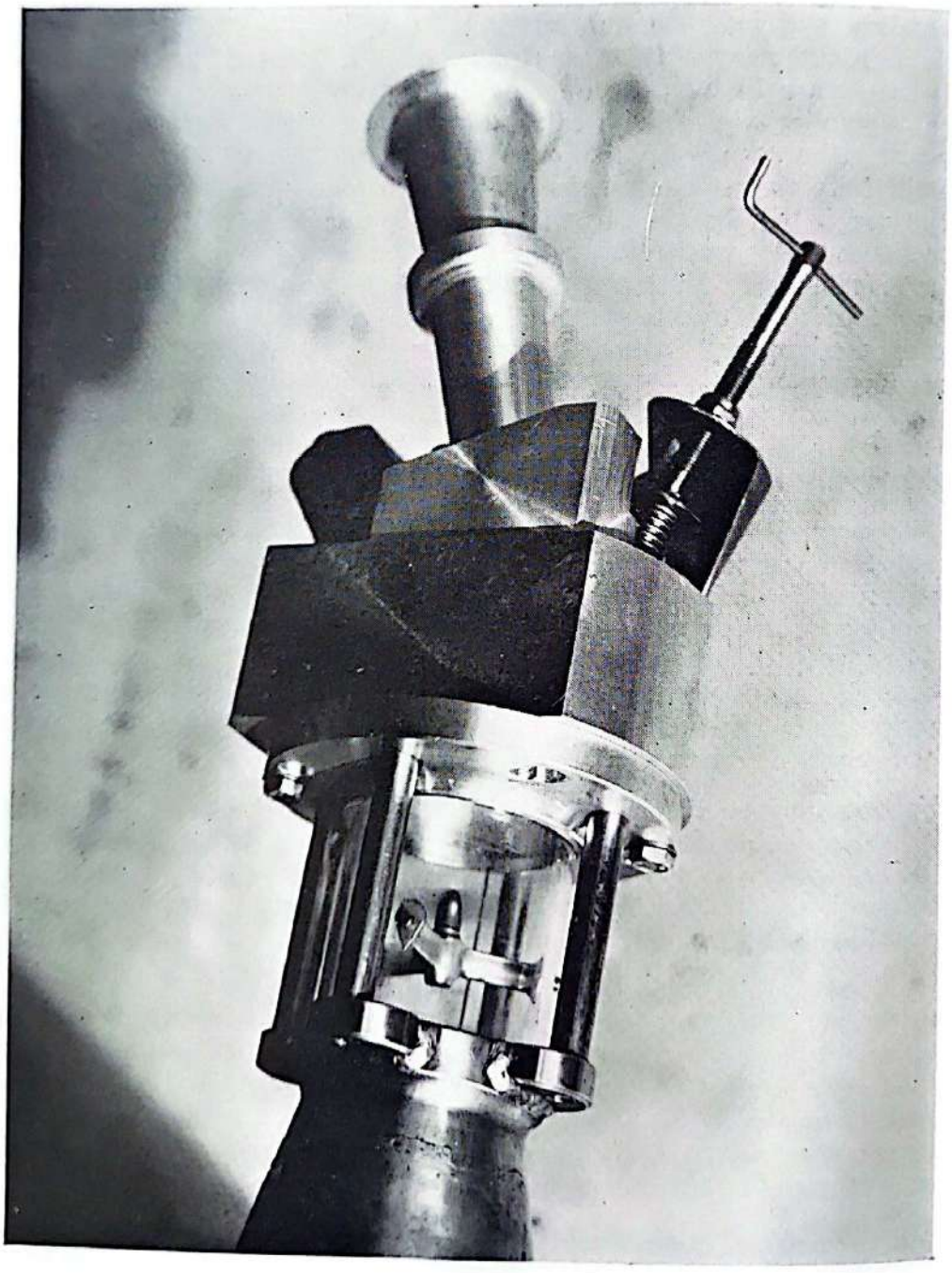


FIG. 15. SWIRL INDICATOR IN USE.

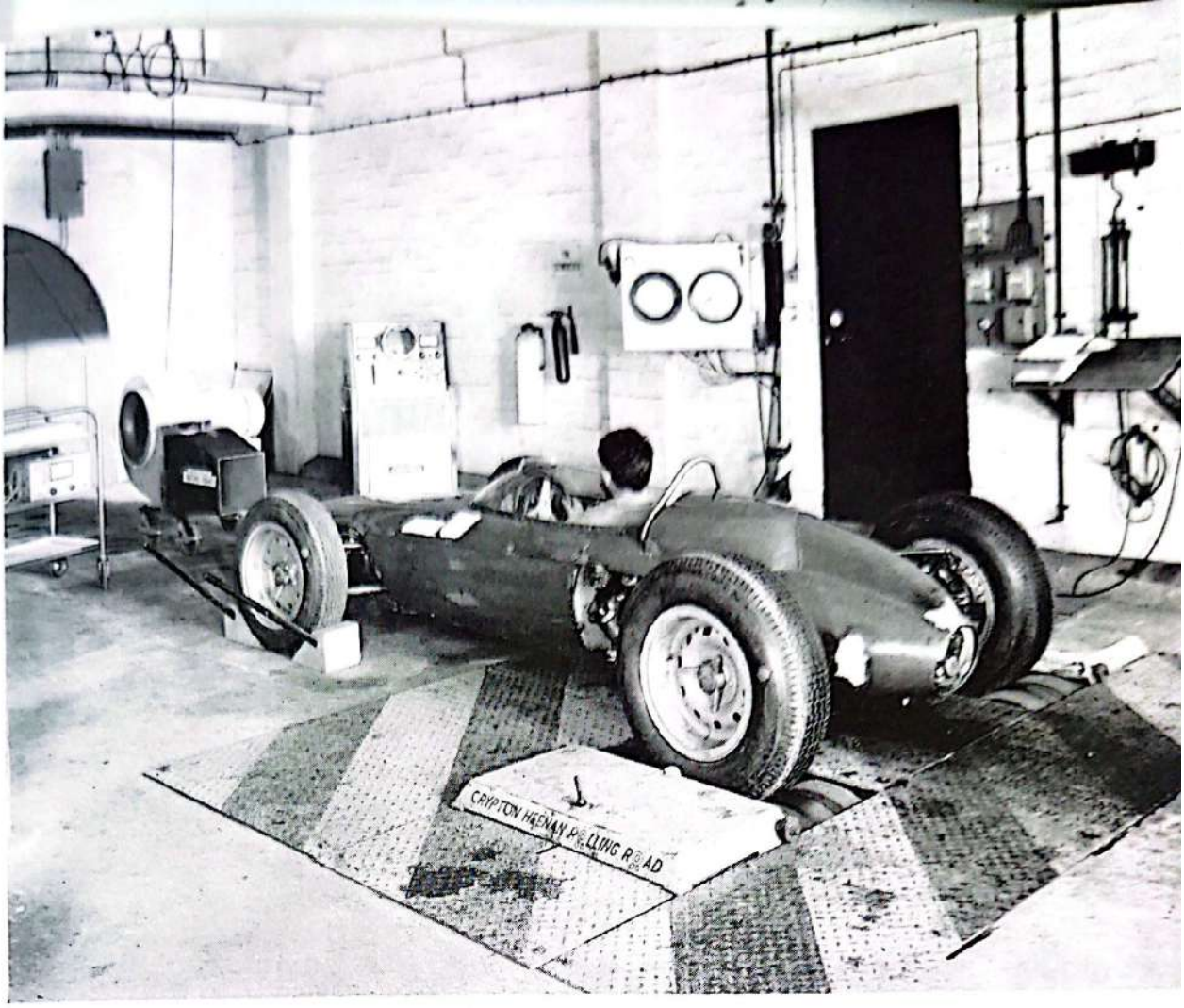


FIG. 16. ROAD WHEEL DYNAMOMETER AT ENGINE DEVELOPMENT DIVISION.

widely different flows. Equally, it has been found that the machine finished port always gives better flow than the traditional hand-finished and polished port.

Road Wheel Dynamometer

This is a relatively new piece of equipment, Fig. 16, and is used principally for evaluating the performance of the oil and water systems, while the engine is underload. The rate of oil circulation of the car oil system can be compared with that of the engine under ideal test bed conditions. Pressure drops can be measured and temperature rises across the oil and air sides of the oil cooler obtained from road testing, can be added in to the results and the effectiveness of the oil system completely evaluated. Similar tests can be applied to the water system.

The more obvious use of a road wheel dynamometer to measure transmission efficiencies brought in its train some problems, notably, that in a high speed road wheel dynamometer the rollers, which make contact with the road wheels, had for safety's sake to be small in diameter; there was a possibility, therefore, that in addition to slip between the tyre and roller that there could be some error due to power absorption through the tyre being in contact with a curved surface of small radius, compared with the virtually infinite radius of the flat road surface. This slip problem was simply disposed of by painting a light patch on the tyre and triggering a stroboflood lamp from the contact roller. It was soon established that in fact slip could be virtually ignored.

Power loss due to tyre deformation as a result of small rollers, was

measured by noting the temperature rise of the tyre and rollers and comparing this with data supplied by the tyre manufacturer. This indicated surprisingly enough that the power loss was in the order of 1 to 1½% per tyre. By measuring engine performance on the dynamometer before and after its performance, complete with its transmission, had been measured on the roller dynamometer, a good idea of transmission efficiency in each gear could be obtained. A problem has been encountered here which has not yet been satisfactorily solved—that is, power outputs are normally corrected to standard temperatures and pressures by the normal British Standards Institution Correction Procedure. It has, however, been found that although this correction procedure appears to give consistent results as far as temperature changes are concerned, changes in Barometric pressures produce wider variations in power than the B.S.I. system seems to indicate. This is apparently the experience of other workers and as yet no satisfactory explanation has been found. It can, however, be said that extreme variations in Barometric pressures—that is, in the order of under 29 or over 30.5", that the B.S.I. correction factor should be nearly doubled.

Other Tests

This covers a wide variety of tests from the water-flow testing of cylinder blocks and cylinder heads, using the bucket and stop watch flow-meter and the water circulating pumps of the dynamometers, and ranges down to deflection tests of connecting rods at different big end bolt torque loadings, using photo-elastic techniques, etc. Static oil flow tests are made of the oil system of an engine, using a remote motor driven oil pump. These are the routine tests — other tests are carried out as circumstances indicate are desirable.

6 AERODYNAMICS

Basic Problems: In the new 1966 3-litre Formula, the field of aerodynamics will probably yield more improvements and benefits than any other area. Of the two principal forces resisting forward motion of the car, rolling resistance from the tyres is approximately a linear law; but aerodynamic drag follows something in the order of a cube law at around 150 miles an hour. It is approximately the power 2.7 and by 200 miles an hour, it is to the power 3.

As it is reasonable to expect the 3-litre cars will be reaching speeds of 200 miles an hour, it is quite obvious that aerodynamics are going to become extremely important. It is sometimes difficult to separate rolling resistance from aerodynamic drag, as it frequently occurs that one of the aerodynamic vices which beset a racing car is that of lift, and as the lift increases it can reach a point where there is no weight upon the road wheels and the rolling resistance is virtually zero.

There is still a great deal of scope for development of methods of measuring aerodynamic forces and drag. Recent developments in the field of miniaturisation of instruments will help tremendously, as in the case of a single-seater racing car there is very little room to spare to accommodate test equipment; and at the moment the various forms of test rigs, such as the wind tunnel, have not been sufficiently calibrated with relationship to the true road behaviour of a single-seater racing car.

There is a further artificial handicap in the field of aerodynamics, and that is, that race regulations have repeatedly specified that the wheels may not be enclosed. Since the frontal area of a non-rotating smooth road wheel is something in the order of 40% of the total frontal area of the car, it can be seen that this poses a tremendous handicap. For example

the 1963 Mark I B.R.M. monocoque had a total drag of .68, whereas the Rover/B.R.M. had a total drag of .32. Most of this can be attributed to the enclosed wheels. There is, however, a further considerable difference, which was again highlighted by a comparison of the turbine car with the piston driven single seater. The turbine car has no radiator; but the piston car has a large radiator, and radiator drag accounted for 40% of the hull drag, which in turn was 60% of the total drag. Yet another problem, is that of air intakes. Any heat engine consumes a large quantity of air and its performance is directly affected by the ease of which it can obtain this air. It can be very simply demonstrated that in the case of a piston engine, travelling at 150 miles an hour, there is a ram pressure which, if it can be properly harnessed, is in the order of half-a-pound per square inch, which in turn is worth some 5% in horsepower on the average piston engine.

Wind Tunnels

This is obviously the basic research tool for the aerodynamic system. Wind tunnels using model techniques are not really satisfactory for use with racing cars. The first obvious shortcoming is that, in practice, the racing car is moving at high speed over a relatively rough road. There is a boundary layer effect on the rough road surface and a similar one under the car. It is virtually impossible to simulate this in a wind tunnel and, therefore, there are considerable discrepancies between scale models in wind tunnels and actual performances. It is this factor (road effect) more than anything else which has led to the appearance of undesirable lift characteristics on high-speed cars, which have been developed from wind tunnel models. Numerous examples of this spring to mind immediately.

Efforts have been made in wind tunnels to simulate the road effect by using a high-speed continuous belt of a rough surface, such as extremely fine emery cloth under the model; but even this has not proved entirely satisfactory.

A second problem which besets the single-seater open wheeled racing car even more than the sports car with enclosed wheels, is that of wheel rotation. The present squat section wide tread tyre is rotating at speeds in excess of 2,000 r.p.m. and the air flung off the relatively rough treads creates a tremendous disturbance, particularly when it is remembered that the top of the tread of a tyre on a racing car travelling at 200 miles an hour, is in fact moving at twice this speed — that is, 400 miles an hour.

There is available the obvious alternative — that is, a wind tunnel into which the complete car or a full-sized mock-up can be tested. This, of course, is astronomically expensive; tests cannot be carried out until either the car, or what is nearly as difficult, a complete mock-up, is completed, and even this suffers from the limitation that in most tunnels the wheels do not rotate. Research workers at M.I.R.A. have discovered that there are discrepancies between results in full-scale tunnels, and even wider discrepancies in results using models of say ¼-scale, between various tunnels; and wider discrepancies still between tests of a model and the full-size car. These are well documented in M.I.R.A. reports.

The procedure followed by the Engine Development Division is to use the model tunnel, to establish some basic characteristics, and then work in a full-scale tunnel to confirm and refine the original ideas. A normal test sequence would be to take a complete car in running order to a full-size wind tunnel, where a number of different nose-shapes were tested. The principles for these different shapes would have been evolved in the

model tunnel. The two or three most promising designs would then be selected by use of the full-size wind tunnel and these would then be confirmed by road tests, which frequently contradict the wind tunnel results.

Valuable information can be obtained by photographing wool tufts, and it is possible by observing the behaviour of wool tufts and the use of pressure probes on the skin of the car to site intakes for engine air, cooling ducts, etc. On the 1965 Owen Organisation B.R.M. monocoque where the exhaust pipes are situated within the Vee, tests weree carried out to determine the most suitable cowling to cover these exhaust pipes, so that some air flow could be reduced for cooling purposes. While these tests were being carried out, it was found that the new location of the exhaust pipes in fact caused 28-lbs. less drag. The exhaust pipes had been relocated to obtain the maximum harmonic benefit from cross coupling, and this additional gain had not been anticipated. The full-size tunnel can also be used to determine the best area for mirrors and also to avoid undesirable eddies and buffeting effects around the driver's head. We have as a result of our experience made two very crude rule-of-thumb generalisations. The first is that full-size wind tunnel results are reliable when applied to areas above the wheel centre lines; as the area under investigation move towards the road, the full-size tunnel results become less reliable. The second of these generalisations is that the car can be divided into three areas for aerodynamic purposes. The first in front of the front wheels is vitally important; the second area behind the front wheels and extending roughly as far as the firewall separating the driver from the engine is still important, but only half as valuable as the area in front of the wheels. The remaining space around the rear wheels is even less important and worth only half as much as the centre section of the car. This is probably the reason why a number of otherwise aerodynamically conscientious racing car designers will quite cheerfully leave off the cowling covering their gearbox.

On the 1964 monocoque Owen Organisation B.R.M. it was found that the tail cowling only contributed 1% to drag improvements. The cowling over the engine approximately 1½%. In practise, it was found that the reduction in engine temperatures gave more power than was liberated by the reduction in drag and, therefore, had race regulations permitted, it would have been better to have run without the cowlings.

In general, the rule is followed that wind tunnel results are reliable insofar as they indicate trends, but the magnitude of those trends or values are far less reliable—for example, testing of the 1964 car showed a lift on the front wheels of approximately 360 lbs. Since under .75 G. acceleration, which is easily possible, there is less than 360 lbs. on the front wheels, in theory the wheels should have become airborne—in fact this did not happen.

Field Testing

This is obviously the most reliable form of testing; and once trends are indicated by the wind tunnel they can be followed up in the field.

The basic method of evaluating any improvement is the coasting test. A series of markers are set up on a suitable straight and the car is driven at a known speed past the first marker. The car is then coasted in neutral to the next marker, with the driver operating a stop watch and determining the time from the first to the second marker. It is necessary to repeat this experiment a number of times as there is a considerable scatter between results. The test is then carried out in the opposite direction, a change made and the tests repeated. If there is an improvement in aerodynamics, obviously the coasting time with the

improvement will be reduced. Again, obviously the higher the speed at which these tests can be carried out, the more accurate the results.

With a single-seater car, with exposed wheels, there is less tendency to lift than a sports car with large expanses of bodywork; but these tendencies, as has already been indicated, are still there. Fortunately, they are easier to observe on the open-wheeled cars by the expedient of painting the wishbones and suspension assemblies white; and with the development of miniaturising techniques with the use of transducers fitted across the suspension struts. The spring rates are known and the average ride height at various speeds gives a good indication of the amount of lift, although generally as the suspension system warms up the car will tend to rise in any case, and, therefore, the datum line should be determined at the end of the test rather than at the beginning.

In theory, the car should be followed by a low-pressure area. This is not always borne out; in fact the original 2½-litre Owen Organisation B.R.M. fitted with a single rear disc, was provided with an air intake to feed cold air to the brake discs, the position of which had been determined by wind tunnel testing. It was also necessary to provide an exit for the used cooling air. Since there was aerodynamic drag, it must follow that there is a low pressure area behind the car and, therefore, any opening cut in the tail should serve as a suitable exhaust, assisted by the pressure difference between the ram air, which had been heated further by the disc, endeavouring to escape into the low pressure area.

The first time, however, the car was run in the rain, it was discovered that rain was entering the tail against the ram pressure of the forward facing cold air intake; and it can be taken that there is generally an area of high pressure around the lower part of the rear face of a car's tail surfaces. This gradually decays and becomes low pressure on the upper edge of the tail surface. If, therefore, the car's exhaust can be arranged to discharge into the centre of this low pressure area, engine efficiency is increased and the drag can be slightly reduced, bearing in mind that it is possible for the average 1½-litre racing engine to discharge something like 1,000 cu. feet of its exhaust per minute into the slip-stream. Intakes to provide air either to the carburettors or fuel injection system are a very rewarding area and are best investigated on the road. In 1959 an intensive series of experiments was carried out by the Owen Organisation in this field. The percentage gain at 150 miles an hour has already been mentioned. In the case of a 2½-litre engine, giving between 250 and 260 h.p. this would be worth at least 12 or 13 h.p. added to which the air will be cold and will further increase the engine's volumetric efficiency, compared with the fouler air which has been heated and diluted when passing under the bonnet.

Two types of intake were investigated — the basic NACA duct, which is a well-known pressure recovery intake, and a simple forward facing duct, similar to that used on low speed aircraft. A sensitive pressure gauge was fitted in the engine intake, close to the carburettors. The application of these techniques is more difficult on the carburettor engine. In a carburettor fuel is drawn from the float chamber into the choke assembly by a very small pressure difference in the order of a few inches of water. If this pressure difference is destroyed by pressures of several feet of water, as can be obtained by ram intakes, it is obvious that the carburettor will not work at all. It is, therefore, necessary to balance the pressures in the float chamber to the air intake in the same way that the carburettor intake itself is connected to the intake. The car was then driven round a test circuit, using various intakes. In a straight line at a speed of 150 miles an hour, there was a gain in intake pressure with the NACA duct of .55 lb. per square inch, and an increase

in speed equivalent to a gain of 15 h.p. This is exactly what could be anticipated from theory, unfortunately as the car braked and negotiated corners at slow speed, large sprays of fuel were observed coming from the intakes where pressure reversals had taken place, due to changes of the car's attitude during braking, and changes in air flow over the duct, due to the front wheels, which were close to the duct, being turned on lock. These problems could not be overcome and, despite its early promise, this intake had to be abandoned. Obviously it would have been very effective on an engine with fuel injection, where pressure reversals and pressure balancing are not required.

Tests on the normal ducted intake, which pass down the side of the bonnet and over the nose of the car, also showed a pressure recovery of .50 of a lb. per square inch at 150 miles an hour. There was, however, virtually no gain in speed, although there were none of the unpleasant side effects of the N.A.C.A. duct. It was decided that the large external box shaped duct winding over the nose of the car was causing aero-dynamic interference, and was spoiling the shape of the car and increasing its drag. Recourse to coasting techniques showed that in fact this was so, and a compromise duct evolved, which recovered .45 lb. per square inch of the dynamic head, and which did not measurably increase the car's drag. The use of this ducting increased the absolute maximum speed of this particular car from 168 to 170.6 miles per hour. Similar experiments were carried out with radiator ducting. It has already been mentioned that the drag of the radiator matrix and its ducts is at least 40% of the hull drag of the motor car. Experiments in the size and shape of the intake to the inlet duct can show many beneficial results. Aircraft experience has already shown that development on the exit duct is even more rewarding, as the air passing through the radiator has been heated; and full exploitation of this technique will yield a forward thrust from the radiator rather than drag. In the average racing car this is not normally possible, as the space for this cannot be spared, either from the point of view of polar moments and handling characteristics and, in any case, the drag from the wetted surfaces of the much longer vehicle out-weighs the gains from the discharge duct. Experiments are now being carried out with side mounted radiators, so that this problem may be overcome in the near future.

As development of a particular car proceeds, it is frequently desirable to provide sources of cooling air for accessories or components, such as shock absorbers. Normal practice is merely to cut a hole in the body-work adjacent to this accessory. More often than not this is totally unrewarding as the hole is cut in an area of low pressure, so that air is drawn out of the car rather than blown in; thus a more scientific approach is necessary.

7. CONCLUSIONS

The writers have tried to segregate and define some of the different areas that make the complex structure of motor racing research. As explained in the beginning, the essentials are those of normal Industrial Research and they become specialised by the environment rather than by any principle. As anyone concerned with research is aware, at any moment of time one does not necessarily think objectively of these principles but without their discipline no progressive development would take place. It would be foolish to deny the importance of the influence of spectator acclaim and its stimulus to the personnel involved. But the fundamental stimulus is the need to advance the science of Automobile Engineering and all that this implies commercially.

APPENDIX 1

GRAND PRIX FORMULÆ, 1906-1966

General

Grand Prix racing (Formula I) is the highest form of motor sport and from the results of the Epreuves, the world's drivers' championship and the world championship of manufacturers are decided. The first race with the title of Grand Prix was held in France in 1898, the first motor race having been held in 1895, from Paris to Bordeaux. Although formulæ had existed prior to 1906, it is usually conceded that the first race **worthy** of the title "Grand Prix" in a modern context was in that year. This had the main features of a race today:—

1. It was run round a circuit and was not a point to point race.
2. There was a formula for the vehicle.
3. It was open to all race-worthy cars and competent drivers of any nation.

Formulae

1906 Engine any size. Any fuel. Maximum vehicle weight stripped, 1,000 kg. plus 7 kg. if magneto fitted.

1907 Maximum fuel consumption 30 litres per 100 km. (9.41 m.p.g.). Any fuel. No vehicle restriction.

1908 Maximum bore 155 m.m. for 4 cylinders, 127 m.m. for 6 cylinders.

1912 Maximum engine capacity 3 litres. Minimum vehicle weight 800 kg. dry. Maximum car width 175 c.m.

1913 Maximum fuel consumption 20 litres per 100 km. (14.1 m.p.g.). Dry weight limits, 800 - 1,100 kg. Streamlined tails banned.

1914 Engine capacity 4½ litres maximum. No forced induction. Any fuel. Minimum vehicle weight 1,100 kg. (The Peugeots were fitted with 4-wheel brakes, the engines developed about 115 b.h.p. with a maximum road speed of 110 m.p.h.).

1921 Maximum engine capacity 3 litres. Any fuel. Minimum vehicle weight 800 kg. (The first American driver to win a Grand Prix was Jimmy Murphy, who won the French Grand Prix at Le Mans in this year. An American did not win again for 40 years. Murphy's Duesenberg was the only American car ever to win a Grand Prix. This Duesenberg was the first Grand Prix car to be fitted with hydraulically operated brakes).

1922 – 1925 Maximum engine capacity 2 litres. Any fuel. Minimum vehicle weight, 650 kg. For 1925 only, minimum width 80 cm. and 2-seater body obligatory, but no mechanic to be carried.

1926 – 1927 Maximum engine capacity 1½ litres. Any fuel. Minimum weight, 600 kg. in 1926 and 700 kg. in 1927. Detailed regulations regarding width.

1928 No engine or fuel restriction. Weight limits 550 - 750 kg.

1929 – 1930 Maximum consumption of fuel and oil, 14 kg. per 100 km. (about 14½ m.p.g.). Commercial fuel

only in 1929 but up to 30% Benzole allowed in 1930. Minimum vehicle weight, 900 kg. Detailed body regulations.

1931 – 1933 Formula libre, that is, any size of car or engine. 10 hour races.

1934 – 1937 No engine or fuel restriction. Maximum dry weight, without tyres, 750 kg. (The objective was to reduce the maximum speed of cars as 150 m.p.h. was considered dangerous, but in practice, 3.7 litre engined cars were competing. By 1937, 6.6 litre).

1938 – 1946 Maximum engine capacity 4½ litres un-supercharged, 3 litres, supercharged. Any fuel. Minimum weight regulations varying with engine capacity. Detailed body regulations, also varying with capacity.

1947 – 1953 Maximum engine capacity 4½ litres un-supercharged, 1½ litres supercharged. Any fuel. (It was to this formula that the original B.R.M. 16 cyl., 1½ litre supercharged engined car was developed. Eventually supercharged at 75 p.s.i., it was producing over 600 b.h.p.).

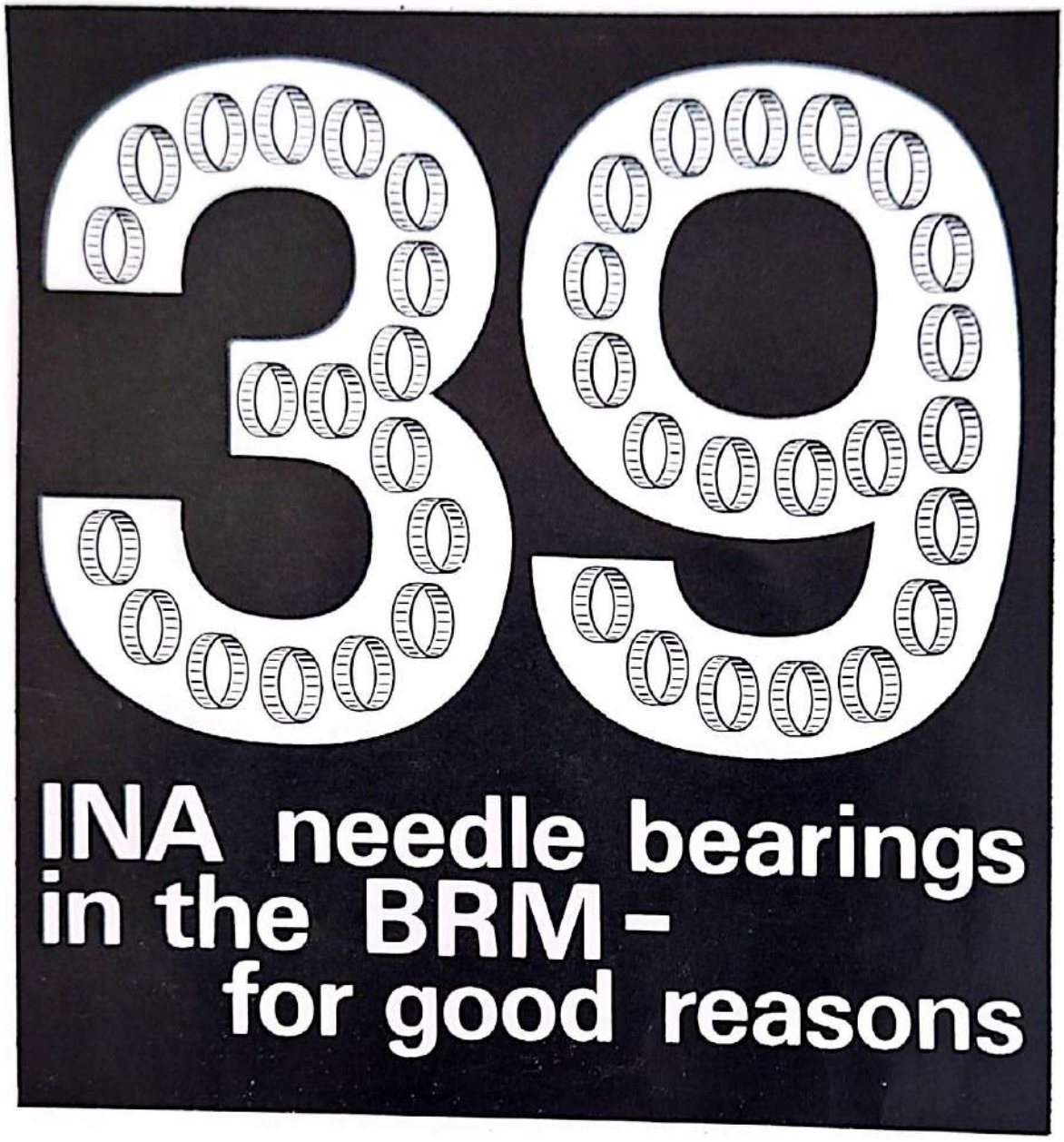
1954 – 1960 Maximum engine capacity 2½ litres un-supercharged, 750 cc. supercharged. No fuel restrictions up to 1957 but from 1958 onward only aviation fuel permitted. (100/130 grade, or AVGAS 2).

1961 – 1965 Engine capacity, 1,301-1,500 cc., un-supercharged. Superchargers not permitted. Commercially available fuell Minimum dry weight, 450 kg. Starter motor and crash hoops mandatory.

1966 Maximum engine capacity 3 litres un-supercharged. 1½ litres supercharged. Commercially available fuel. Minimum weight, 500 kg. and other regulations, as 1961 - 1965. Gas turbine engines allowed on a formula equating to equivalent piston engine capacity.

Points of Interest

1. Until 1938, the advantage of a supercharger was not fully realised apparently by those framing regulations, and they could be used without any restriction on engine capacity.
2. For many years it was obligatory to have a driver and travelling mechanic, with a combined weight of not less than 120 kg. From 1925 onwards, the carrying of a mechanic was forbidden. Apart from 1929 - 1930, single seater bodies have been allowed since 1927.
3. Up to 1957, with the exception of 1929, there were no restrictions on fuel and any mixture could be used. From 1961, commercially available fuel safe-guarded by various regulations, has been obligatory. In practice this means a fuel very close to a standard premium grade of 100 octane and helps in ensuring that racing engine development is aligned to general automobiles. Commercial fuel is defined as being freely available at roadside pumps in the country of car's origin or country where race is held.
4. Certain formulae have not been popular. From 1928 - 1930 the formula was largely ignored and most races were "Formula Libre"



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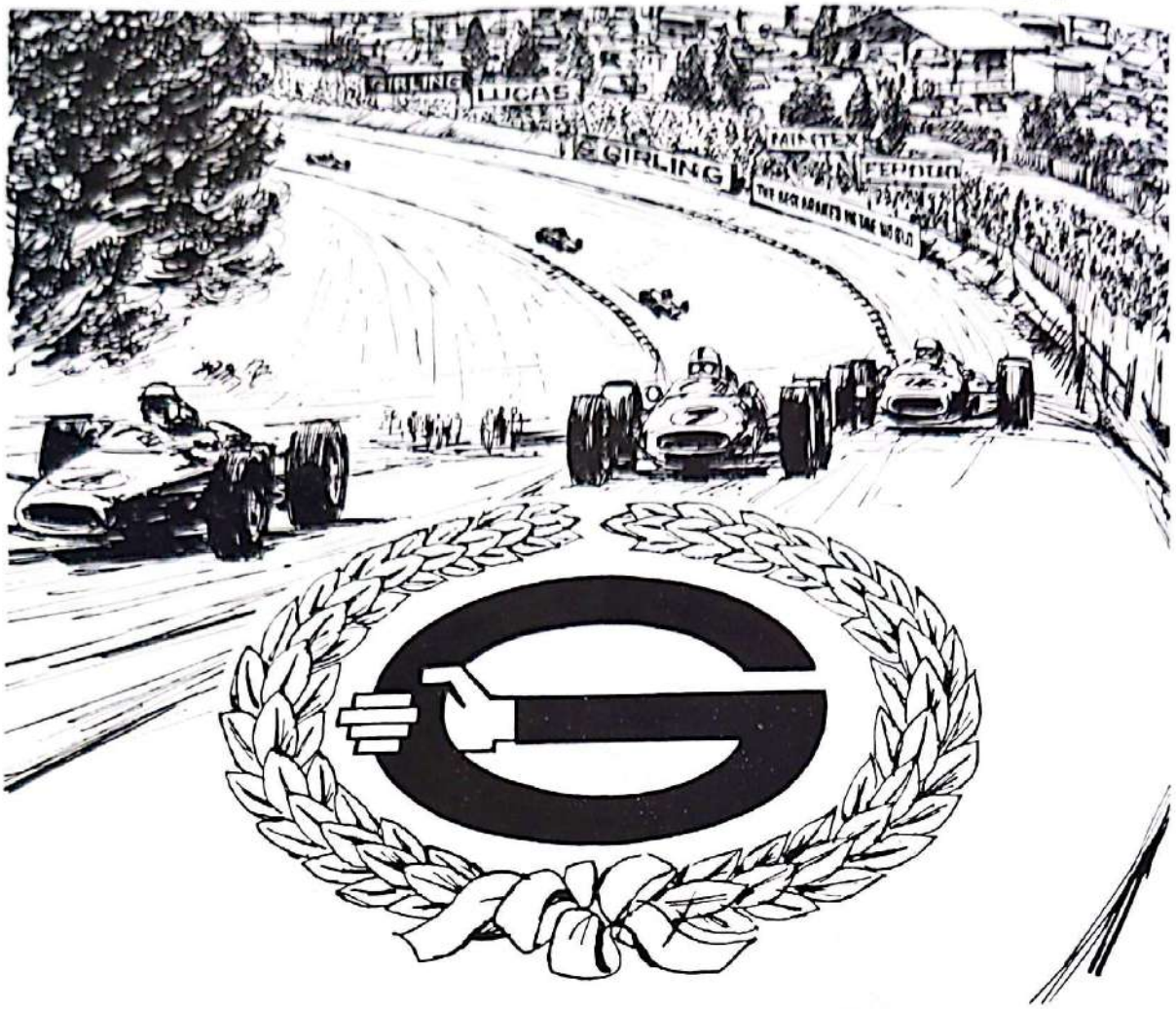

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or for sports cars. In 1952 and 1953 most of the major races, including those counting for the world's drivers' championship, were held under Formula II.

5. Minimum distances and/or times have been specified over recent years for the Grandes Epreuves counting for the world championships. These are:—

1928 – 1930	600 km. (373 miles).
1931	10 hr. (!)
1932	5 - 10 hr.
1933 – 1940	500 km. (311 miles).
1950 – 1957	300 km. (186 miles) or 3 hr.
1958 – 1965	300 - 500 km. (186 - 311 miles) and 2 hrs.
1966	300 - 400 km. (186 - 248 miles).

6. The concept of what is today known as Formula II dates back to the beginning of Grand Prix racing. Before the 1914-1918 Great War, the equivalent of Formula II cars were running in the same races as Formula I; this was the formula for the Coupe de l'Auto. In 1907, for example, the formula was similar to that for the larger cars, but with the fuel consumption limited to 15 litres per 100 Km

APPENDIX 2

SOME SIGNIFICANT DATES IN COMPONENT DEVELOPMENT

The following are a few significant dates in the development of cars for the higher forms of automobile racing. They mark the successful application of devices rather than their historical emergence. It will be realised that the general commercial application to mass production cars lags several years behind. For example, disc brakes were used on Grand Prix and Le Mans cars in the early 1950's: they then appeared on high performace sports cars but their application to popular cars is of recent origin. Even today a complete disc brake system on all wheels is a rarity.

1906	High tension magneto ignition (Renault).
1907	Front wheel drive (Christie, U.S.A.).
1912	Four valves per cylinder, hemispherical cylinder heads and double overhead camshafts (Peugeot).
1913	Sleeve valves and last use of side valves in Grand Prix racing.
1914	Four wheel brake systems.
1920	Light alloy pistons and multiple carburettors.
1921	Hydraulic brakes using glycerine/water mixture (Dusenberg).
1922	Scientific aerodynamic bodies. Desmodromic valve gear and magnesium pistons.
1924	Light alloy wheels.
1934	Independent suspension of all four wheels.
1936	Ability to drift (Mercedes W.125).
1950	Disc brakes.
1959	High hysterisis tyres.
1962	British fuel ignition on Grand Prix cars and use of alternators.
1963	Gas turbine powered car completes race distance (Rover-B.R.M.).
1965	Gas turbine powered car placed in a race (Rover-B.R.M., first British car and 10th overall at Le Mans).

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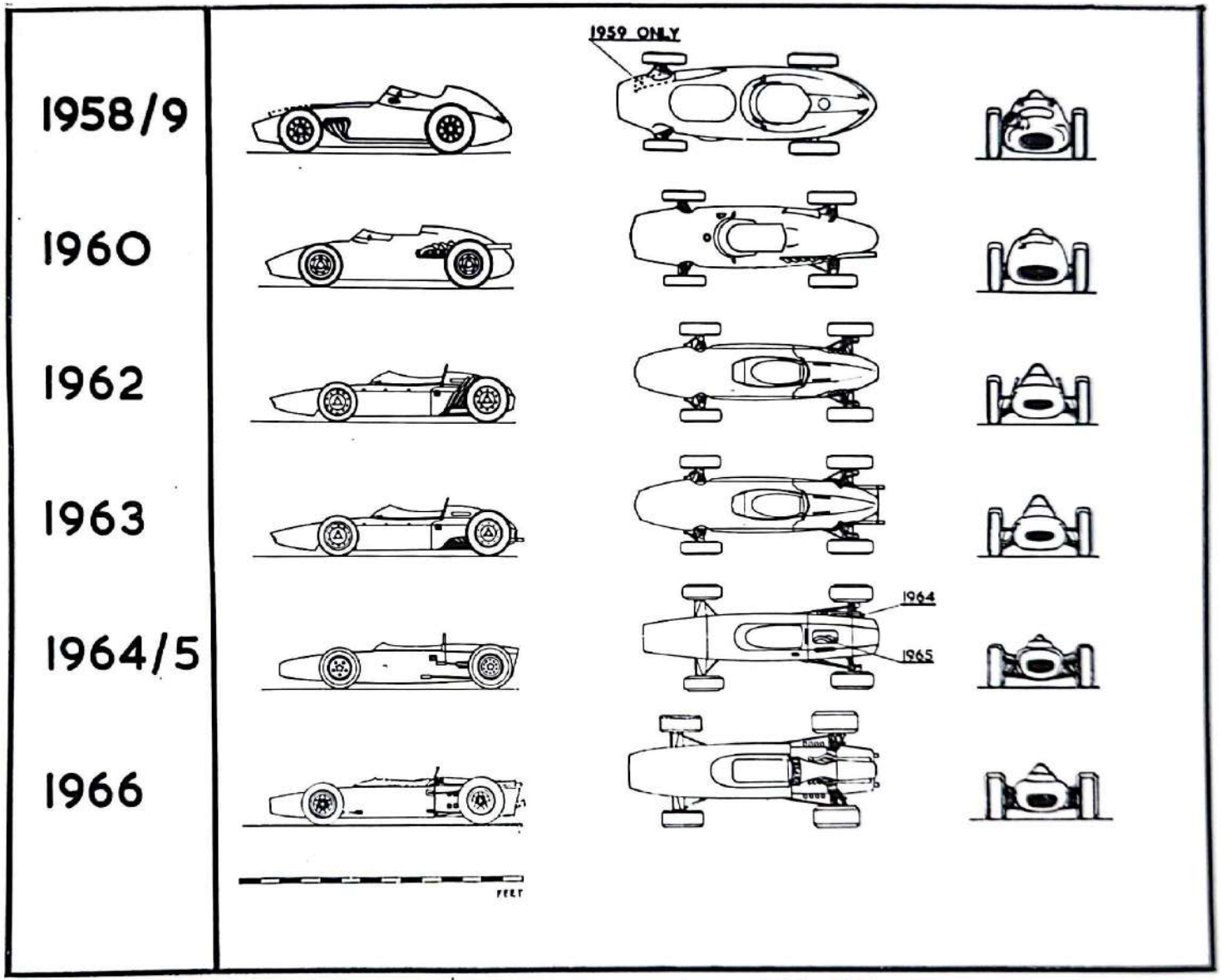
APPENDIX 3

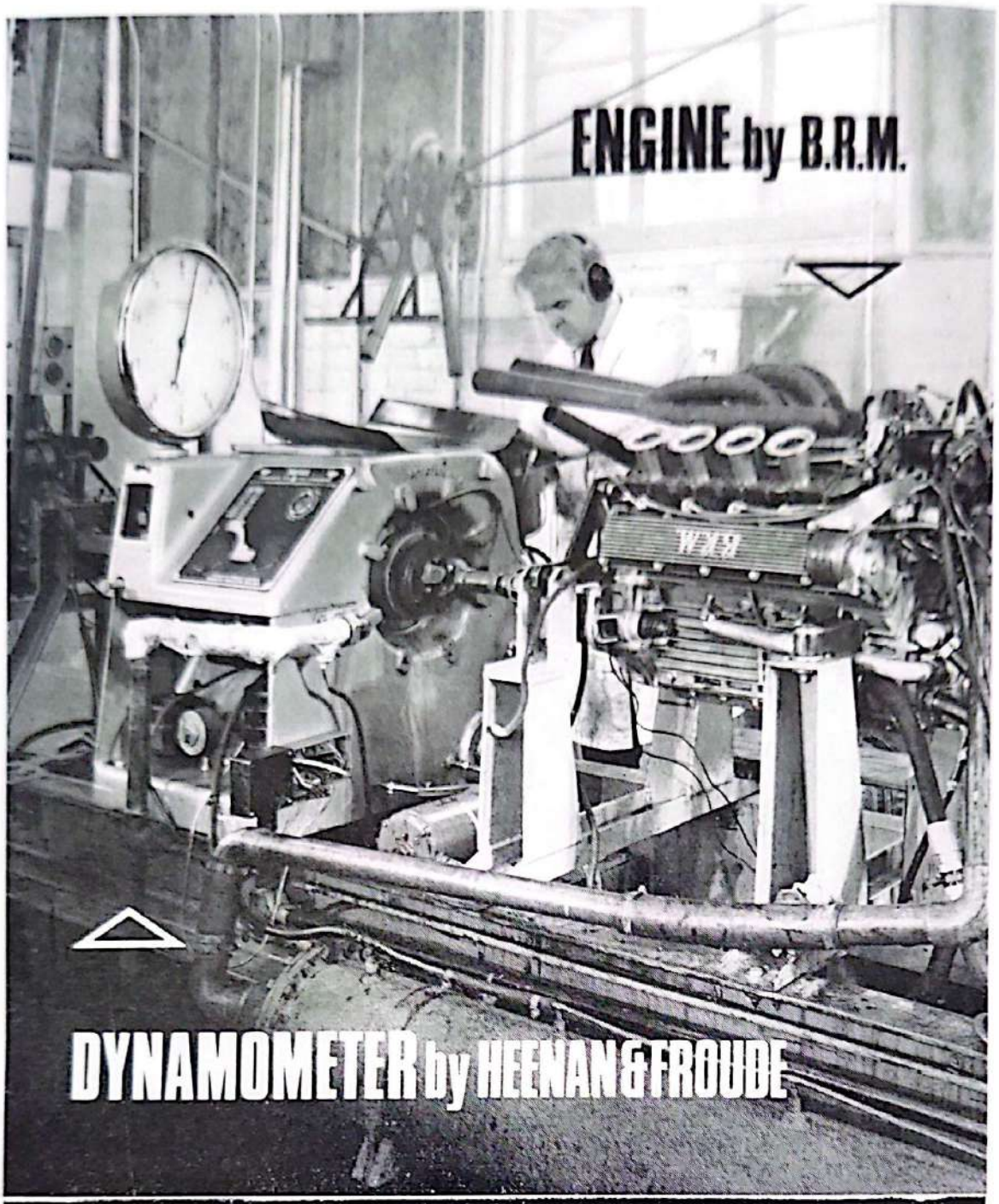
B.R.M. FORMULA 1 CAR COMPARISONS 1958-1966

Designation	Units	1958/59	1960	1962/63	1964/65	1966
Engine Size	litre	2½	2½	1½	1½	3
Overall Length	in.	154.5	147	147	145	154 may be reduced
Overall Height	in.	43	37	35.1	32	32 "
Overall Width	in.	58	59	60.75	63.35	69.6
Wheelbase	in.	89	88.5	89.82	91	94 "
Front Track	in.	50.5	50.5	52.5	55	56.5
Rear Track	in.	52	51.0	52.175	52.75	56.5
Tyre Sizes Front	in.	5.50 x 16	5.25 x 15	5.50 x 15	5.50 x 13	5.50 x 14
Tyre Sizes Rear	in.	7.00 x 16	7.00 x 15	7.00 x 15	7.00 x 13	7.00 x 14
Dry Weight	lbs.	1350 - 1380	1280	1085	1050	1200
Frontal Area Body	sq. ft.	10.97	8.18	4.82	3.95	4.51
Wheels	sq. ft.	3.33	3.32	3.30	3.75	5.06
	H.P./sq. ft.	14.3	11.50	8.12	7.70	9.57
Power per unit area		18.2	22.60	24.60	26.6	41.8
Power per unit weight	H.P./Ton	426	455	413	437	800

Estimated Values



PROFILES OF B.R.M. FORMULA 1 CARS 1958—1966.



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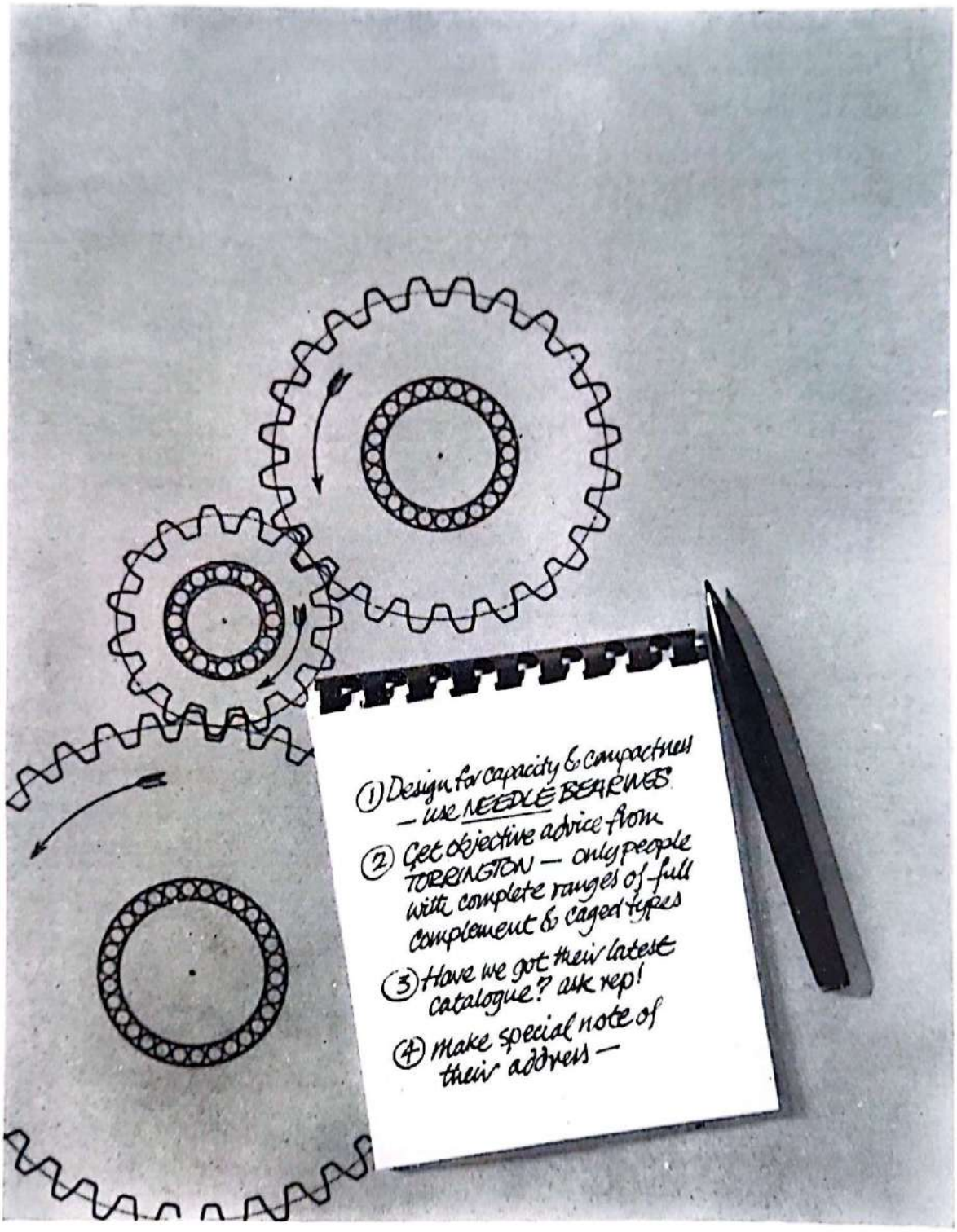
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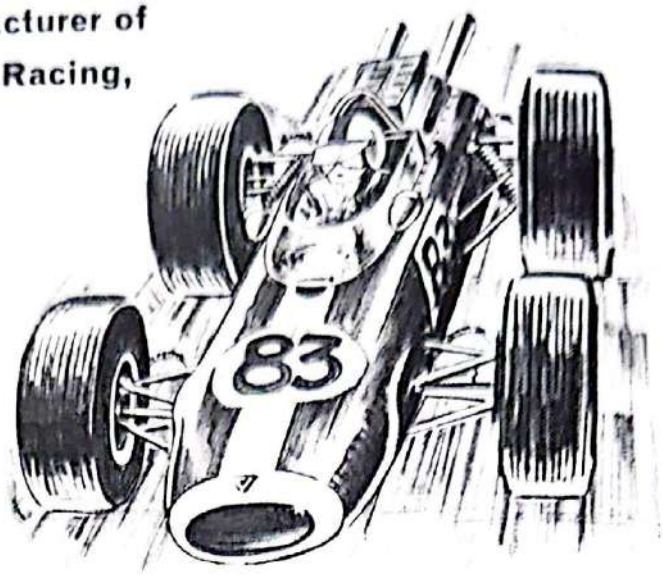

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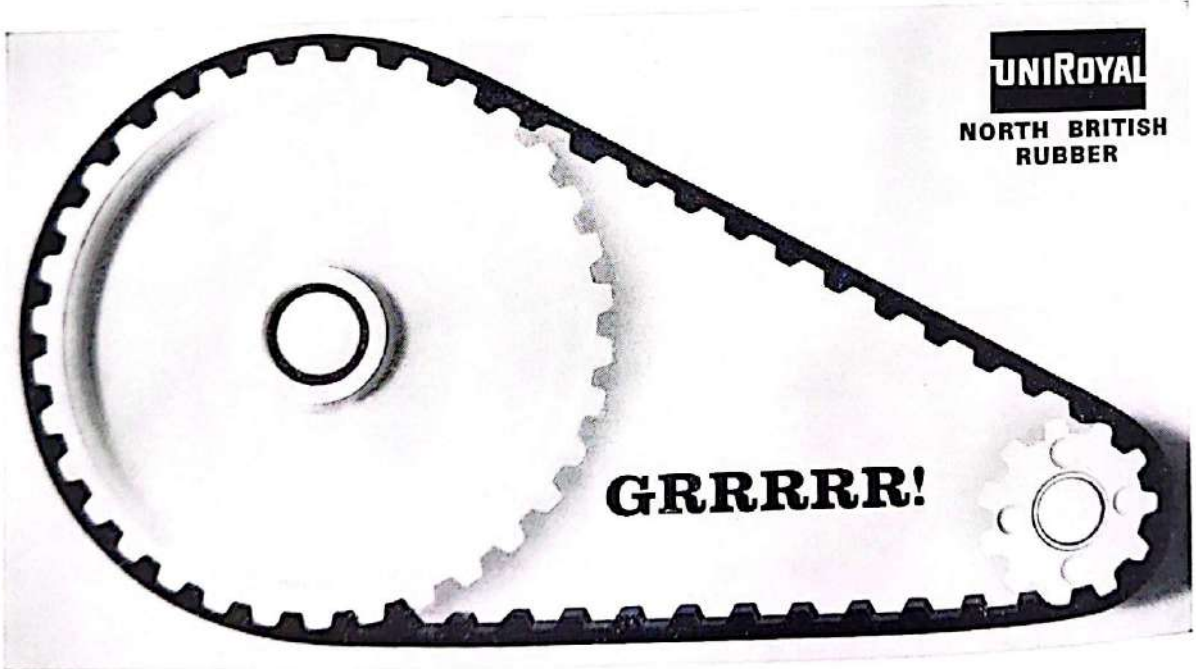

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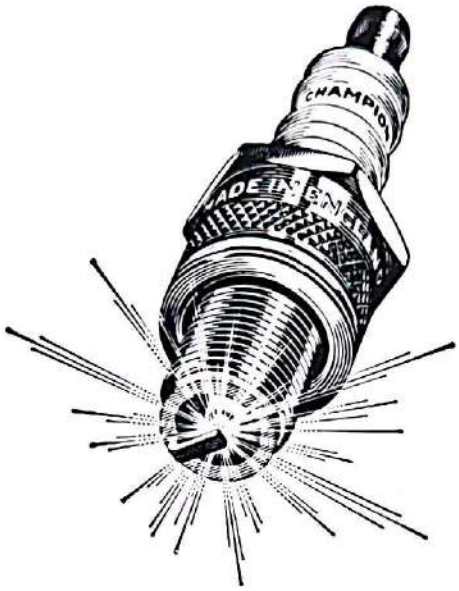

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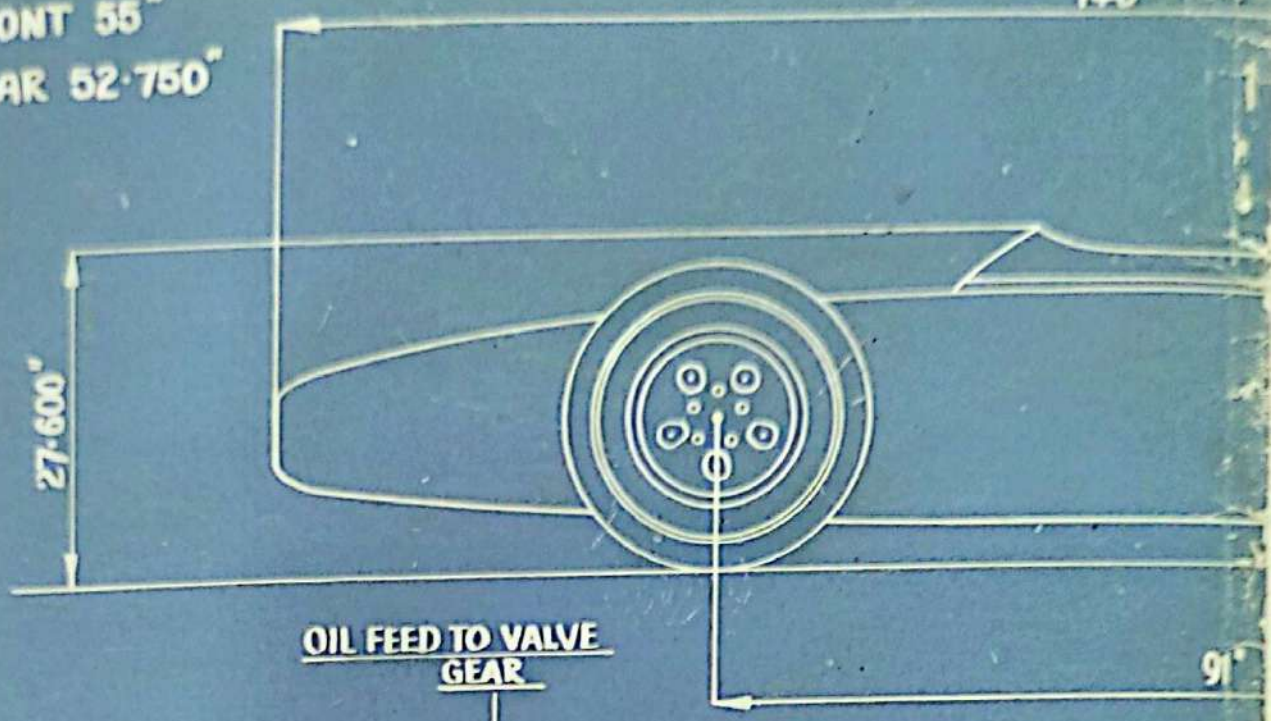

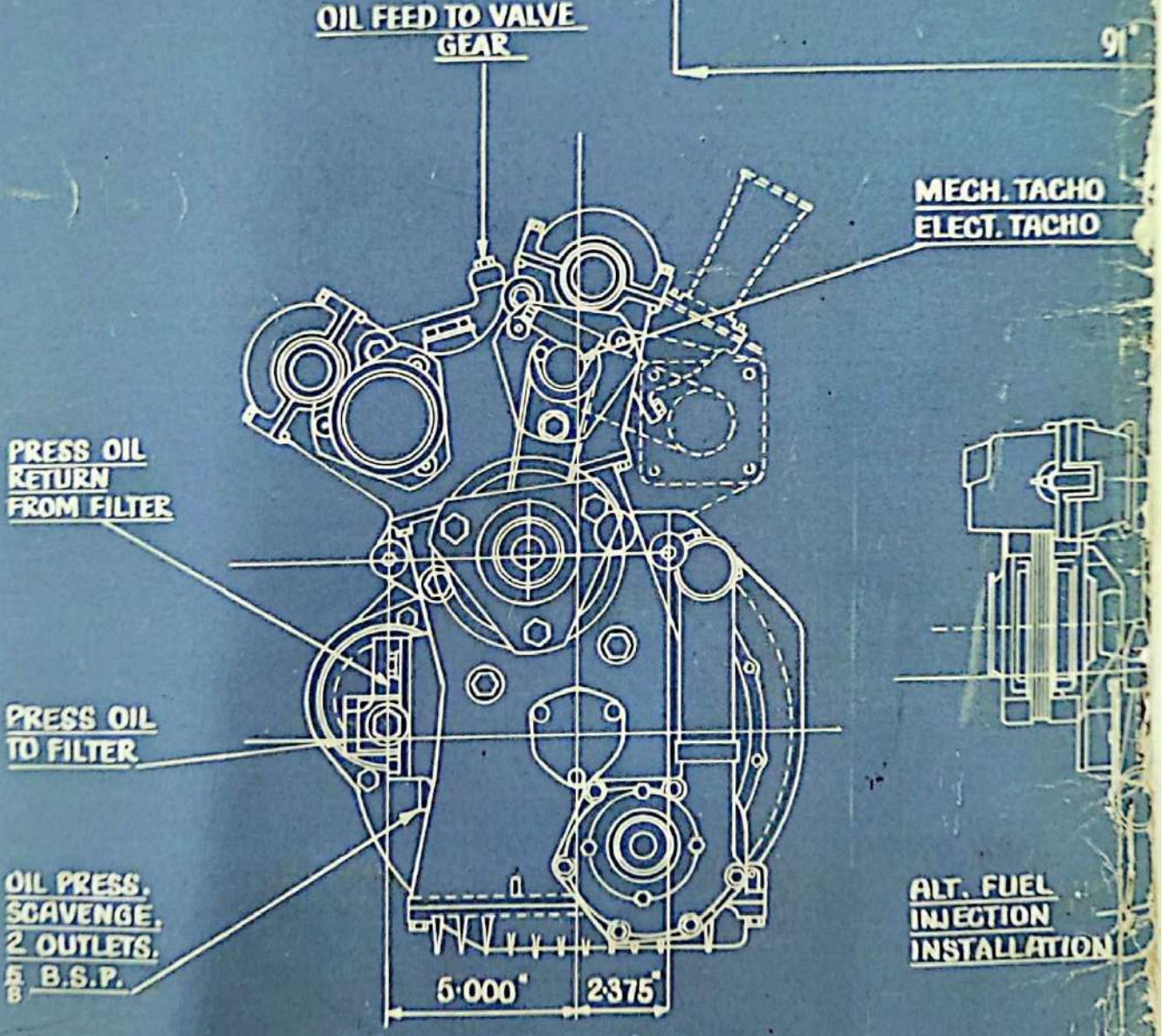

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